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OF THE
IRON AND STEEL INSTITUTE

VOL. LV.

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BENNETT H. BROUGH
SECRETARY

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THE IRON AND STEEL INSTITUTE.

SECTION I.

MINUTES OF PROCEEDINGS.

ANNUAL GENERAL MEETING.

THE ANNUAL GENERAL MEETING of the IRON AND STEEL INSTITUTE was held at the Institution of Civil Engineers, Great George Street, London, on Thursday, May 4, 1899—E. P. MARTIN, Esq., the Retiring President, in the chair.

The SECRETARY read the Minutes of the previous Meeting, which were confirmed and signed.

Mr. BEAUMONT THOMAS and Mr. C. P. SANDBERG, Jun., were nominated Scrutineers, and on the completion of their scrutiny reported that the following gentlemen had been duly elected as members of the Institute:—

| NAME. | ADDRESS. | PROPOSERS. |
|-----------------------|--|--|
| Abbott Vernon Francis | Wigan Coal and Iron Company, Wigan, Lancs. | Alfred Hewlett, John Wood, T. M. Percy. |
| Ångström, Carl . . . | Motala Werkstad, Sweden | Richard Åkerman, Axel Wahlberg, Jonas C : son Kjellberg. |
| Atkinson, John F. . . | Milton House, Dore, near Sheffield | A. J. Jordan, Jno. G. Lowood, Franklin Hilton. |

| NAME. | ADDRESS. | PROPOSERS. |
|--|---|--|
| Baillie, James Richard | 1 Akenside Road, Hampstead, London, N.W. | Philip Williams, Cecil H. Pearson, Jas. J. Wallis. |
| Bates, Henry . . . | 30 Halliwell Terrace, Trafford Road, Salford | S. R. Platt, Henry Webb, Thomas Ashbury. |
| Bellamy, Alfred Rowe | Fordsburg, Edgeley, Stockport | Henry Webb, Thomas Ashbury, F. Monks. |
| Berglund, Henrik . . | Lesjöfors, Sweden | Richard Åkerman, Axel Wahlberg, Jonas C : son Kjellberg. |
| Bildt, Carl Wilhelm . | Washburn and Moen Manufacturing Company, Worcester, Mass., U.S.A. | Richard Åkerman, Axel Wahlberg, Jonas C : son Kjellberg. |
| Bohman, Knut Otto Alfred | Stockholm, Sweden | Richard Åkerman, Axel Wahlberg, Jonas C : son Kjellberg. |
| Bowman, Harold . . | Stevenson & Co., Canal Foundry, Preston | Edward Barton, Bernard Dawson, Sir William H. Bailey. |
| Brittain, Harry Ernest, B.A. | Alma Works, Sheffield | Joseph Gamble, G. Senior, Robert Colver. |
| Brown, H. Walter . . | Dore, near Sheffield | G. E. Howland, Arthur S. Lee, Albert Senior. |
| Brown, Peter Boswell | Hecla Works, Sheffield | R. A. Hadfield, A. G. M. Jack, E. Wheatecroft. |
| Cadman, James Cope | Silverdale, North Staffordshire | Jos. Cook, George North Adams, Ernest Farnworth. |
| Coleman, William Wheeler | South Bethlehem, Pennsylvania, U.S.A. | T. M. Drown, R. W. Davenport, J. Fritz. |
| Cordner-James, John Henry, Assoc. M. Inst. C.E. | Finsbury House, Blomfield Street, London, E.C. | Bedford McNeill, R. E. Commans, F. W. Harbord. |
| Cornelius, Gustaf . . | Stockholm, Sweden | Richard Åkerman, Axel Wahlberg, Jonas C : son Kjellberg. |
| Creswick, Alfred Jubb | Gatefield House, Sheffield | Jno. G. Lowood, J. J. Pickford, William Tozer. |
| Daniel, Edgar Llewelyn | 15 Oaklands Terrace, Swansea | Ernest Trubshaw, E. Rice Daniel, Francis T. Thomas. |
| Demenge, Emile . . | 89 Avenue de Villiers, Paris | A. Tannett Walker, Lewis J. Firth, E. Clavay Chalas. |
| Disdier, Enrique . . | Bilbao, Spain | Edw. P. Martin, E. Windsor Richards, A. Tannett Walker. |
| Donechay, James . . | Tipton Green House, Tipton, Staffs. | W. Moore, Alfred Colley, Wm. P. Cardell. |
| Edmunds, Henry . . | 2 Queen Anne's Gate, London, S.W. | Fred Smith, Geo. H. Smith, A. Tannett Walker. |
| Edwards, James Harry | High Docks, South Shields | J. Cartmell Ridley, Jeremiah Head, Henry Fownes. |
| Ewing, James Alfred, D.Sc., F.R.S., M.Inst. C.E. | Langdale Lodge, Cambridge | Sir William C. Roberts-Austen, Sir Frederick Abel, George J. Snelus. |

| NAME. | ADDRESS. | PROPOSERS. |
|---|---|---|
| Footner, Harry, M.Inst.C.E. | Dee Fords, Chester | Edw. P. Martin, E. Windsor Richards, A. Tannett Walker. |
| Foss, Theodore | Sormovo Steel Works, Nijni-Novgorod, Russia | R. A. Hadfield, A. G. M. Jack, Ernest Wheatcroft. |
| Galloway, Edward N. | Knott Mill Iron Works, Manchester | Sir Richard Mottram, Arthur W. Galloway, W. E. Nor- bury. |
| Griffiths, Thomas . . . | Glanmôr, Burry Port, Carmarthenshire | David Evans (Middles- brough), Isaac Butler, Edwin Richards. |
| Hammond, Joseph . . . | The Hollies, Wollaston, Stourbridge | Sir Benjamin Hingley, William Hutchinson, Joseph Waddington. |
| Hunt, Robert W. | 1137 Rookery, Chicago, U.S.A. | Edward P. Martin, E. Wind- sor Richards, A. Bowen. |
| Isakson, Carl Johan Albert | 46 Skeppsbron, Stock- holm, Sweden | Tom Bergendal, Arent Silf- versparre, J. Svedberg. |
| Jansson, Gustav | Munkfors, Sweden | Charles H. Morgan, Henry M. Howe, E. Windsor Richards. |
| Jessup, Alfred E. | Sparrow's Point, Mary- land, U.S.A. | Henry M. Howe, R. A. Had- field, Edward P. Martin. |
| Kerpely, Anton von . . | Kampnerstrasse 55, Vienna, Austria | David Evans (Middles- brough), J. Stephen Jeans, James Williard Miller. |
| Kidd, Henry Charles . . | Foundry and Shell Factory, Cossipore, Calcutta | R. A. Hadfield, A. G. M. Jack, J. M. Ledingham. |
| Kirkham, William . . . | Rock House, Brins- worth Street, Atter- cliffe, Sheffield | David Evans, Harry Marsden, James Banham. |
| Kirkhouse, Herbert . . | Bryn Bedw, Ponty- pridd, Glamorgan- shire | Edward P. Martin, Sir William T. Lewis, W. Thomas. |
| Kockum, Frans Henrik | Malmö, Sweden | Richard Akerman, Axel Wahlberg, Jonas C : son Kjellberg. |
| Kuzu, Kuraji | Cyclops Works, Shef- field | Sir Alexander Wilson, Frederick Stubbs, Petro- nius Hodges. |
| Lloyd, Albert William | The Farm, Spark- brook, Birmingham. | John Francis Pease, Francis H. Lloyd, Alex. E. Tucker. |
| Lundström, Arnold Fredrik | Gref Magnigatan 11, Stockholm, Sweden | C. Danielsson, Aug. Her- lenius, Jonas C : son Kjellberg. |
| Magnuson, Tord | Sandviken, Sweden | Richard Akerman, Axel Wahlberg, Jonas C : son Kjellberg. |
| Maw, Francis John . . . | 87 Burngreave Road, Sheffield | Sir Alexander Wilson, Petro- nius Hodges, Frederick Stubbs. |
| Melling, John Frederick | Cyclops Steel Works, Sheffield | Sir Alexander Wilson, Frederick Stubbs, Jno. G. Lowood. |

ELECTION OF MEMBERS.

| NAME. | ADDRESS. | PROPOSERS. |
|--|---|--|
| Milne, C. Williamson | 3 Crown Court, Old Broad Street, London, E.C. | Sir James Kitson, Bedford McNeill, H. W. Hollis. |
| Musgrave, John Raven | Richmond Hill, Whitehaven | Thomas Barlow-Massicks, Augustus Helder, Charles Hornung. |
| Östberg, Petter . . . | Stockholm, Sweden | Richard Åkerman, Axel Wahlberg, Jonas C : son Kjellberg. |
| Platts, John Charles, F.I.C., F.C.S. . . . | 54 Marlborough Road, Moor Oaks, Sheffield | John D. Ellis, George S. Packer, T. E. Freeston. |
| Ridge, Joseph . . . | Tudor Works, Sheffield | A. J. Jordan, Jno. G. Lowood, William Jas. Gardner. |
| Rooth, Theodor. . . | Surahammar, Sweden | Richard Åkerman, Axel Wahlberg, Jonas C : son Kjellberg. |
| Saladin, Edouard . . | Schneider & Co., Le Creusot, France | R. A. Hadfield, Eugène Schneider, M. Geny. |
| Storey, Thomas William Patrickson, M.Inst. C.E. . . . | Mostyn, Flintshire | J. T. Smith, S. Sutcliffe, W. J. P. Storey. |
| Svedberg, Sven . . . | Hellefors, Sweden | Richard Åkerman, Axel Wahlberg, Jonas C : son Kjellberg. |
| Syed Ali Bilgrami, Shamsul Ulama, B.A., LL.B., F.G.S., Assoc. R.S.M. | Hyderabad Deccan, India | Sir W. C. Roberts-Austen, H. G. Turner, Sir Lowthian Bell. |
| Wesselhoeft, H. . . | Düsseldorf, Germany | E. Schrödter, R. M. Daelen, Fritz W. Lürmann. |
| Yngström, Lars . . . | Domnarfvet, Sweden | E. J. Ljungberg, Carl Sahlin, A. G. Ljungberg. |

The SECRETARY then read the following Report of the Council upon the proceedings of the Institute during the year 1898 :—

REPORT OF COUNCIL.

At this thirtieth Annual General Meeting of the Iron and Steel Institute, the Council have the pleasure of presenting to the members their Report on the proceedings of the Institute, and are glad to note that the Institute has during the year 1898 maintained its prosperous and satisfactory condition.

THE ROLL OF THE INSTITUTE.

The number of members on the roll of the Institute on December 31, 1898, was—

| | | | | | | | |
|------------------|---|---|---|---|---|---|-------------|
| Honorary members | . | . | . | . | . | . | 8 |
| Life members | . | . | . | . | . | . | 8 |
| Ordinary members | . | . | . | . | . | . | 1506 |
| Total | . | . | . | . | . | . | <u>1522</u> |

During the past year there have been added to the register 98 names, a number in excess of the average of the previous five years, as will be seen from the figures given below—

| Year. | New Members. |
|-------------------|--------------|
| 1893 | 45 |
| 1894 | 114 |
| 1895 | 93 |
| 1896 | 80 |
| 1897 | 88 |
| Average | <u>84</u> |
| 1898 | 98 |

To the list of Honorary Members the names of H.M. King Oscar II. of Sweden and Norway, and of Baron Gustav Tamm, Governor-General of Stockholm and President of the Association of Swedish Ironmasters, have been added during the year.

The Council have to congratulate several members of the Institute who have had high distinctions conferred upon them. Professor Sir William C. Roberts-Austen, President-elect, has been promoted to be a Knight Commander of the Most Honourable Order of the Bath, and a

Knighthood has been conferred upon Sir David Richmond, Lord Provost of Glasgow. The honorary degree of Master of Arts has been conferred by the Columbia University upon Mr. John Fritz, Bessemer Gold Medallist and Honorary Member of the Iron and Steel Institute, in recognition of his services to metallurgy. The Senate of the University of Glasgow has conferred upon Mr. William Jacks the honorary degree of Doctor of Laws. Mr. W. H. Massey has been appointed by the King of the Belgians a Commander of the Order of Leopold. Mr. M. Géný has been appointed a Knight of the Legion of Honour. Mr. Fritz Baare has had conferred upon him by the German Emperor the Cross of the Royal Prussian Order of the Crown; and Mr. H. Lueg, on the occasion of the opening of the new Rhine Bridge, was accorded the title of Geheimer Kommerzienrath. Captain G. Dyrssen has been appointed Swedish Minister of Marine; Mr. C. Lundeberg has been elected Deputy-Speaker of the Upper House of the Swedish Parliament; and the King of Sweden has conferred upon Mr. A. Silfversparre the Cross of the Royal Order of the Northern Star. Mr. W. H. Butlin has had conferred upon him by the Queen Regent of Spain the Cross of the Royal Order of Isabella the Catholic.

During the year under review the Institute has suffered great losses by the death of many of its distinguished members, the following forty deceases of members having been reported:—

| | |
|---|--------------|
| Alley, Stephen (Glasgow) | March 23. |
| Anderson, Sir William (Woolwich) | December 11. |
| Bain, Sir James (Glasgow) | April 25. |
| Beckwith, John Henry (Stockport) | June 2. |
| Bessemer, Sir Henry (London) | March 15. |
| Biot, Auguste (Rio de Janeiro) | May. |
| Blair, Thomas S. (Pittsburgh) | October 22. |
| Chambers, Arthur Marshall (Sheffield) | August 29. |
| Clark, George Thomas (Glamorgan) | January 31. |
| Cochrane, Charles (Pedmore). | May 11. |
| Dorman, Robert Page (Middlesbrough) | October. |
| Douglass, William (Blaydon-on-Tyne) | May 23. |
| Dunkerley, C. Chorlton (Bowden) | July 22. |
| Dyer, Henry Clement Swinnerton (Manchester) | March 21. |
| Frey, Ritter Carl August von (Germany) | February 2. |
| Gjers, John (Bournemouth) | October 6. |
| Gotteschalk, Philippe Alexandre (Paris) | February 21. |

| | |
|--|--------------|
| Herbert, Charles (Swansea) | June 5. |
| Hulse, Joseph Whitworth (Manchester) | April 21. |
| l'Anson, James (Darlington) | March 30. |
| Jost, Adolphe (Sheffield) | October 23. |
| Lindheim, Wilhelm von (Vienna) | January 28. |
| Lloyd, William Ellis (Birmingham) | June. |
| M'Lachlan, Thomas (London) | June 27. |
| Mudd, Thomas (Hartlepool) | May 20. |
| Pease, Arthur (Darlington) | August 27. |
| Rendel, William Stuart (London) | May 4. |
| Richards, F. Windsor (Leeds) | January 22. |
| Richards, Lewis (Glamorgan) | April 23. |
| Ridley, Thomas Dawson (Coatham) | January 13. |
| Salomon, Fritz (Essen) | October 26. |
| Schneider, Henri Adolphe Eugène (Le Creusot) | May 17. |
| Shenton, James (Hyde) | June 25. |
| Squire, Edward L. (Shropshire) | April 21. |
| Stoker, Frederick William (Johannesburg) | January 22. |
| Storey, Sir Thomas (Lancaster) | December 13. |
| Thomson, Grahame Hardie (Glasgow) | September. |
| Wells, William Edwin (Mossbrough) | November 29. |
| Williams, James (Malpas) | August. |
| Wrightson, Stephen (Carnforth) | December 3. |

The following death of a member occurred in 1897, but was not noted in the Council Report for that year :—

Ellis, Thomas Leonard (Coatbridge) March 27, 1897.

Of these deceased members, Sir Henry Bessemer, the man whose name has become a part of the English language, was one of the founders of the Institute, and always took a warm interest in its welfare. He was elected President in 1870, and in 1885 Trustee of the Institute's invested funds. He founded the Bessemer Gold Medal, and presented to the Institute his collection of early specimens of Bessemer steel, dating back to August 1856. Mr. G. T. Clark was elected a Trustee of the Institute funds in 1880. Mr. John Giers received the Bessemer Gold Medal in 1894. Mr. Schneider, the great French iron-master, received the Bessemer Gold Medal in 1889. Particulars of the professional careers of the deceased members will be found in the obituary notices published in the Journal of the Institute.

In consequence of the non-payment of subscriptions, the names of ten members have been removed from the list, and there have been twenty-five resignations of membership. °

FINANCE.

The statement of accounts for the year 1898 is now submitted to the members by the Honorary Treasurer. It will be observed that the income for the year amounted to £3985, and the expenditure to £3989. The income was in excess of that of last year. The expenditure, owing to the publication of the General Index and to the fact that the Autumn Meeting was held abroad, also showed an increase.

The corresponding figures for the five previous years were as follows :—

| | Income. | | | Expenditure. | | |
|--------------|---------|----|----|--------------|----|----|
| | £ | s. | d. | £ | s. | d. |
| 1893 | 3589 | 11 | 0 | 3899 | 15 | 2 |
| 1894 | 3749 | 3 | 3 | 3074 | 1 | 9 |
| 1895 | 4159 | 7 | 5 | 3088 | 6 | 7 |
| 1896 | 3891 | 12 | 11 | 4338 | 14 | 11 |
| 1897 | 3937 | 5 | 8 | 3207 | 10 | 3 |
| Average . . | 3865 | 8 | 0 | 3521 | 13 | 9 |

Sir David Dale, Bart., Past-President, and the Right Honourable Lord Wimborne were elected Trustees in May 1898, and the Institute's invested funds have been duly transferred to Sir Joseph Pease, Lord Wimborne, and Sir David Dale.

MEETINGS.

Two general meetings were held as usual during 1898. The Spring Meeting, on May 5th and 6th, was held at the Institution of Civil Engineers, whose constant courtesy in providing accommodation demands grateful acknowledgment.

The Autumn Meeting was held in Sweden, a country not previously visited by the Institute. The members were received with magnificent hospitality by an influential Local Committee, under the Presidency of Baron Gustav Tamm, Governor-General of Stockholm and President of the Swedish Association of Ironmasters, and the Swedish ironmasters vied with one another to afford to the members of the Institute all the instruction and hospitality possible. To Dr. Richard Åkerman, Director-General of the Board of Trade, Colonel J. Geijer, Mr. C. C. Lindberg, Mr. E. J. Ljungberg, and Mr. J. C. Kjellberg, the

members of the Executive Committee, the warmest thanks are due. The excursions which preceded and followed the meeting were most instructive, and have been described at length in the Journal of the Institute. After the meeting the Council arranged for the presentation of pieces of plate to the members of the Executive Committee as souvenirs of a visit which, from the brilliancy of its success, the great cordiality of the reception, and the warmth of the hospitality, is not likely soon to be forgotten by the members. Special brilliancy was given to the meeting by the presence of His Majesty King Oscar of Sweden and Norway, who graciously took part in the Institute's deliberations, and received the members at his palace of Drottningholm. His Majesty was also pleased to consent to be enrolled as an Honorary Member of the Institute.

The titles of the papers contributed to the Institute's proceedings during the year were as follows :—

1. On the Use of Blast-Furnace Gas for Motive Power. By A. GREINER.
2. On Coking in By-Product Ovens. By J. H. DARBY.
3. On the Relative Merits of Limestone and Lime in Blast-Furnace Practice. By C. COCHRANE.
4. On Steel Permanent Way. By R. PRICE-WILLIAMS.
5. On the Iron Ore Deposits of the Ural. By H. BAUERMAN.
6. On the Crystalline Structure of Iron and Steel. By J. E. STEAD.
7. On Allotropic Iron and Carbon. By E. H. SANITER.
8. On Brittleness in Soft Steel. By C. H. RIDSDALE.
9. On the Solution Theory of Iron and Steel. By the Baron H. JÜPTNER VON JONSTORFF.
10. On Outlines of the Development of the Swedish Iron Industry. By R. ÅKERMAN.
11. On the Most Prominent and Characteristic Features of Swedish Iron Ore Mining. By G. NORDENSTRÖM.
12. On the Danger of Using too Hard Steel Rails. By C. P. SANDBERG.
13. On the Iron Ore Deposits of Kiirunavaara and Luossavaara. By H. LUNDBOHM.
14. On Experiments made with a Motor using Blast-Furnace Gas. By A. WITZ.
15. On Brittleness produced in Soft Steel by Annealing. By J. E. STEAD.
16. On the Micro-Chemistry of Cementation. By J. O. ARNOLD.
17. On the Action of Metalloids on Cast Iron. By G. R. JOHNSON.

18. On the Action of the Projectile and of the Explosives on the Tubes of Steel Guns. By Sir WILLIAM ROBERTS-AUSTEN.
19. On the Solution Theory of Iron and Steel. By the Baron H. JÜPTNER VON JONSTORFF.
20. On the Diffusion of Sulphides through Steel. By E. D. CAMPBELL.

The annual dinner of the members of the Institute was held on May 5, 1898, in the Grand Hall of the Hotel Cecil. The chair was taken by the President, and amongst the noblemen and gentlemen present were His Excellency the Swedish and Norwegian Minister, Lord Claud Hamilton, Lord Wimborne, the Honourable E. Lyulph Stanley, Sir William H. White, K.C.B., the Presidents of many of the kindred societies, and a large number of members and their friends.

PUBLICATIONS.

Of the Journal of the Institute two volumes have, as usual, been published, containing together 1230 pages of letterpress and 59 plates. In addition to the papers read before the Institute, and the discussion and correspondence relating to them, the volumes contain 1388 abstracts of papers relating to iron and steel and kindred subjects published in other home and foreign technical Journals and Transactions.

The members also received during the year an Index to the first fifty volumes of the Journal, a bound volume of 564 pages.

LIBRARY.

Numerous presentations to the Library have been made, a list of which is given in the Journal of the Institute. For these the Council record their thanks to the several donors. A volume of exceptional interest has been presented to the Institute in compliance with the wishes of the late Mr. Charles Cochrane by his executors. It consists of his original manuscript records of experimental work in connection with the blast-furnace.

The additions to the collection of portraits include a large portrait, painted in oil by Mr. Rudolph Lehmann, of the late Sir Henry Bessemer, Past-President, presented by the executors; a pastel portrait of Sir Lowthian Bell, Bart., Past-President, presented by that gentleman; a portrait of the late Mr. G. T. Clark, presented by the President; and a portrait of Sir David Dale, Bart., Past-President, presented by that gentleman.

APPOINTMENT OF REPRESENTATIVES.

The Right Honourable Sir Bernhard Samuelson, Bart., Past-President, gave evidence on behalf of the Iron and Steel Institute before the National Physical Laboratory Committee, on the question of the desirability of establishing a National Physical Laboratory; and the President, Sir Lowthian Bell, Bart., Past-President, and Sir James Kitson, Bart., M.P., Past-President, were appointed to represent the Institute at the Jubilee of the French Society of Civil Engineers on June 10, 1898. The Institute was also represented at the Jubilee of the Austrian Society of Engineers in Vienna by the Secretary, who presented a congratulatory address from the Institute, in which reference was made to the hospitality accorded to the Institute by the Austrian Society on the occasion of the memorable visit to Vienna in 1882.

PETITION FOR A ROYAL CHARTER OF INCORPORATION.

It having been determined that it would be for the advantage of the Institute to obtain incorporation under a Royal Charter, a committee, consisting of the President, the President-elect, Sir Lowthian Bell, Bart., Past-President, the Right Hon. Sir Bernhard Samuelson, Bart., Past-President, Sir James Kitson, Bart., M.P., Past-President, Sir E. H. Carbutt, Bart., and Mr. W. Whitwell, Hon. Treasurer, was appointed. A draft charter was prepared by Messrs. Bircham & Co., and is now under the consideration of the Privy Council.

RETIRING MEMBERS OF COUNCIL.

The Members of Council who retire in rotation are—

Vice-Presidents.

Sir Wm. Thomas Lewis, Bart. Sir J. G. N. Alleyne, Bart.
Mr. G. J. Snelus, F.R.S.

Members of Council.

Mr. F. W. Webb. Sir A. Hickman, M.P.
Mr. J. E. Stead. Sir E. H. Carbutt, Bart.
Mr. S. R. Platt.

As no other candidates have been nominated, these gentlemen, who are all eligible, are presented by the Council for re-election.

The Hon. Treasurer (Mr. WILLIAM WHITWELL) submitted the Annual Statement of Accounts for the year 1898 as follows:—

THE IRON AND STEEL INSTITUTE.

ACCOUNT OF INCOME AND EXPENDITURE FOR THE YEAR ENDED DECEMBER 31, 1898.

| INCOME. | | EXPENDITURE. | |
|--|------------|---|------------|
| To Entrance Fees | £203 14 0 | By Salaries | £1169 0 0 |
| " Subscriptions | 3227 14 0 | " Office Rent, Cleaning, &c. | 387 7 7 |
| " Life-Compositions | 63 0 0 | " Library Books and Binding | 47 1 7 |
| " Journal Sales | 192 2 0 | " Office Furniture | 34 4 7 |
| " Interest on Investments | 283 13 11 | " Annual Meeting Expenses (London) | 57 14 1 |
| " Bessemer Medal Fund Interest | 15 9 8 | " Autumn Meeting Expenses (Stockholm) | 382 0 1 |
| | £3985 13 7 | " Journal Publishing Expenses :— | |
| | | Printing | £904 4 5 |
| " Balance, being excess of Expenditure over Income | 4 3 1 | Abstracts | 175 0 0 |
| | | Translation of Papers | 30 19 6 |
| | | Postage | 82 5 11 |
| | | General Index | 318 2 0 |
| | | | 1505 11 10 |
| | | Postage and Receipt Stamps | 108 10 0 |
| | | " Printing and Stationery | 264 19 7 |
| | | " Insurance | 1 15 0 |
| | | " Bessemer Medal | 15 5 0 |
| | | " Corporation Duty | 14 18 0 |
| | | " Sundry Payments | 57 16 4 |
| | | " Auditor's Fee | 13 13 0 |
| | £399 16 8 | | £3980 16 8 |

BALANCE SHEET, DECEMBER 31, 1898.

| LIABILITIES. | | ASSETS. | |
|--|------------|--|-----------|
| To Sundry Creditors:— | | By Subscriptions in arrear for 1898, since received | £89 0 0 |
| " Printing Journal | £442 17 10 | " Subscriptions in arrear for 1897, &c., since received | 6 6 0 |
| " Postages | 40 10 1 | | |
| " Journal Abstracts | 25 0 0 | " Interest on Investments accrued, due at 31st December 1898 | 143 8 8 |
| " Translations | 5 5 0 | " Journal Sales, since received | 86 4 0 |
| " Autumn Meeting | 3 0 0 | " Cash at Bank | 442 2 7 |
| " Library Books | 8 0 5 | " Do. in hands of Secretary | 200 0 0 |
| " Printing and Stationery | 4 15 6 | | 642 2 7 |
| Subscriptions received in advance | £229 8 10 | | |
| Iron and Steel Institute Capital Account at 1st January 1898 | 21 0 0 | | |
| Less Excess of Expenditure over Income transferred from Income and Expenditure Account | £401 1 0 | | |
| | 386 18 5 | | |
| | £2017 7 3 | | £2947 7 3 |

INVESTED FUNDS OF THE INSTITUTE.

| | |
|--|-----------|
| £3744 North-Eastern Railway 4 per cent. Preference Stock, purchased at a cost of | £4287 6 7 |
| £788 North-Eastern Railway 4 per cent. Guaranteed Stock, purchased at a cost of | 1008 14 0 |
| £1544* Sclade, Punjab, and Delhi 5 per cent. Stock, purchased at a cost of | 1099 0 7 |
| £750 Great Indian Peninsula Railway 5 per cent. Stock, purchased at a cost of | 1267 6 0 |
| | £8572 7 2 |

* This has since been compulsorily converted into "B" annuities of £79, 4s. 5d., expiring 1953, with a Sinking Fund to replace the amount of Stock.

(Signed) WILLIAM WHITWELL, *Hon. Treasurer.*
BENNETT H. BROUGH, *Secretary.*

BESEMER MEDAL FUND.

£534 London and North-Western Railway 3 per cent. Debenture Stock.

I have examined the above Accounts with the Books and Vouchers of the Institute, and certify it to be correct. I have also verified the Balance of the Bankers' Account, and examined the Securities for the Invested Funds as shown above.

(Signed) W. B. KEEN,
Chartered Accountant.

3 CHURCH COURT, OLD JEWRY, E.C., 3rd May 1899.

On the motion of the President, seconded by Sir Lowthian Bell, Bart., Past-President, the Report of the Council and Statement of Accounts were unanimously adopted.

Mr. SEPTIMUS VAUGHAN MORGAN, on behalf of the members of the Institute, proposed a vote of thanks to the President and the Council for their services during the past year.

Mr. G. AINSWORTH (Consett) said he had the greatest pleasure in seconding that resolution. Their thanks were due, and should be very cordially given, to the President and Council for their services during the past year. The Council, as they had learnt from the report, were undoubtedly guiding the Institute in a most able way. Not only was the number of members steadily increasing, but financially they were getting into a very sound and stable position. As regarded the President, he did not think the opportunity ought to be let pass without saying a word as to the capable and able manner in which he had fulfilled his duties. He had certainly continued with undimmed lustre the long chain of able and clever Presidents who had presided over them since the establishment of the Institute; and he would also like, as one who had had the pleasure of taking part in the meeting in Sweden, to add his testimony particularly to the exceedingly capable way in which the President had carried out his duties on that occasion. Not only had he represented the Institute with dignity when in royal presence, but at all the meetings he had presided with the greatest ability, and on these occasions their Scandinavian friends, he ventured to say, were as much struck by his geniality, affability, and general good temper, as they themselves had been impressed by the unbounded hospitality of their friends in Sweden. There was one point which he thought all of them noted more particularly, and that was the great aptitude he had displayed in being able to make a speech on any and every occasion, whether it was at seven o'clock in the morning or at ten o'clock at night. He not only had the happy talent of being able to make speeches, but also one that they envied him very much, namely, that of being always able to

talk sense. He had, therefore, very great pleasure in seconding the motion.

The resolution was put and carried with acclamation.

The PRESIDENT, on behalf of the Council and himself, begged leave to thank the members of the Institute for the very kind manner in which they had acknowledged the services rendered by the Council during the past year; and on his own behalf he begged to thank both the Council and the members sincerely for the great kindness and support which had been accorded him at their hands during his term of office. When, two years ago, he had accepted the honourable and onerous position of President of the Institute, he accepted it with great hesitation and diffidence, but thanks to the assistance and the kindness that had been shown him on all sides by Past-Presidents, the Council, the members themselves, and the staff, he retired to-day almost with a feeling of regret, but at the same time feeling exceedingly thankful to find that during the past two years the Institute had not suffered, but had enjoyed exceptional prosperity. The members had increased in number by 186, and their income was greater than in any two previous years. Their proceedings had been most interesting, and the publication of a careful and voluminous index had greatly assisted in making these proceedings more accessible to the members. The autumn meetings at Cardiff and Stockholm were both brilliantly successful, and Welsh and Swedish hospitality had vied with each other. During his presidency the King of Sweden, who had graciously taken part in their proceedings in Stockholm, had been pleased to consent to be enrolled an honorary member of the Institute. Her Majesty the Queen had honoured their President by bestowing on him a medal to be worn in commemoration of Her Majesty's Diamond Jubilee. But there were two great events which it would always be his pride, and he was sure that of his successors as well, to be associated with. One of these was the charter which they hoped that Her Majesty the Queen, with the advice of her Privy Council, would grant them. The other was the recognition which their industry had obtained during her reign; and as it would be the formal

duty of his successor to make this announcement, he need only say how very glad he was that an event of so much importance, should occupy so prominent a place in both their terms of office. He regretted, and he was sure that every member would regret, that the founder of this medal, Sir Henry Bessemer, had not been spared to be present to-day to hear that announcement. It was now his duty and great pleasure to induct the new President into the chair, and in doing so he felt confident that with so eminent a man of science as Sir William Roberts-Austen, who had done so much to bring science and practice together, and with the hearty support which he felt sure he would receive from all the members, the lustre and distinction that had always attached to the chair would be fully maintained.

Sir WILLIAM ROBERTS-AUSTEN, K.C.B., who was received with loud applause, thanked the members most sincerely for the warmth of their reception. He well knew how difficult it would be to succeed a President who not only endeared himself to every member of the Council, but who had won the affection—he did not think it too strong a term to use—of each individual member of this great Institute. It would only be by following as closely as he could in Mr. Martin's footsteps that he could hope to attain to even a portion of his success. He then delivered the following address :—

PRESIDENTIAL ADDRESS.

THE announcement that HER MAJESTY THE QUEEN will be graciously pleased to accept the Bessemer Medal for 1899, in commemoration of the progress made in the Iron and Steel Industries during her reign, will be received with enthusiasm throughout the Empire. What the progress has been it will be my privilege to indicate in this address; for your last President of the century, in bidding it a respectful farewell, must offer the best retrospective tribute he can to the grandest industry in the world's history.

This address will, therefore, be mainly devoted to the consideration of British efforts in connection with iron and steel. I shall hope on another occasion to pay homage to the services rendered in other countries to our branch of metallurgy, but in view of our Autumn Meeting last year at Stockholm, I cannot proceed further without making a brief reference to Sweden. To her scientific men our debt is great and of long standing, for we have profited by their labours from the eighteenth century until now. We appreciated the interest in our proceedings which was shown by the presence of His Majesty the King and the Royal Princes at our meetings in the Riddarhus. The gracious kindness of His Majesty during the magnificent reception at his palace of Drottningholm will never be forgotten by those of us who were present. The spontaneous warmth of our reception by the Swedish people also touched us deeply, and the memories of our visit will be handed down as traditions to future members of our Institute, who, in the days to come, will, we trust, again seek the aid of Sweden by supplementing the ores of our own possessions with those from within the Arctic circle.

* It seems strange to us now to be reminded that when the nineteenth century dawned the primitive home of the iron industry in Kent, Surrey, and Sussex had not been abandoned. From my Surrey garden I look towards the tract once covered

by the great forest of Anderida, within the bounds of which coal has recently been discovered. The survivors of the ancient trees of Andreds Wald still give shelter to a few charcoal-burners, the pursuit of whose occupation connects us with the past. There is almost within sound of me as I write, a stream that fed one of a series of hammer-ponds, and the district within sight is believed to have furnished the coffer for the Doomsday Book, and it certainly did the iron which encircles the cathedral of our great city. The domain has further claim to remembrance, for it supplied guns for the cruisers of Drake and Frobisher. In 1740 there were four more blast-furnaces in Sussex than in any other county; in 1800 there were still two at work, and the one at Ashburnham survived until 1828, producing iron for which the claim was made that it was "in no wise inferior to the Swedish metal." These old charcoal-furnaces could rarely have exceeded 28 feet in height, with an output of some 20 tons a week. Even the greatly improved furnaces adopted about the year 1839 by John Gibbons in South Wales, did not exceed 40 feet in height; and although they were considered to be "enormous," they did not make more than 120 tons weekly. As the century closes, some of their gigantic successors, such as those possessed by our Vice-President, Mr. Andrew Carnegie, produce *daily* no less than 748 tons of iron, and much of the material which issues from them is destined to undergo complex and varied methods of treatment.

From a hill near me I can look over most of the southern home of the iron trade, and I have lingered in the reference to it because a similar comprehensive glance over the landmarks of our industry is all that time will permit me to offer you. Compared with the long past of the simple methods of extracting iron from its ore which in the South of England preceded the use of even charcoal-furnaces, the duration of modern and complex methods seems to be little more than an episode. The age of steel has not as yet endured fifty years, and tracing its rise shows that the entire history of our industry, like that of humanity, is an account of its continual changes. How did progressive development—that is, a change from the relative uniformity of primitive direct reduction processes to those of relative complexity—take place? The change is mainly due to

the efforts of individuals stimulated by the country's needs. It was effected by a few men who had the courage to lay aside traditions which had been handed on for generations, and possessed the determination to make costly and laborious experiments for themselves. They were men who, being untrammelled by precedent, called in question the utility of established usages, and their endurance enabled them to solve in a new way problems of vast metallurgical importance. How could the leading British ironmasters of the first half of the nineteenth century be hindered by conventionalism when their mission was to shape the industrial life, not only of their country, but of the world? Progress was made by intellects such as our country has always had in her hours of industrial need. Both the technical workers and the experimenters in the domain of pure science were inspired by the spirit of progress, and their aim was identical. Hence the blending of efforts. Watt, Stephenson, and later Bessemer, Siemens, and others of our own body, became Fellows of the Royal Society, while a Chancellor of the University of Cambridge, and founder of the Cavendish Laboratory, was chosen as first President of the Iron and Steel Institute.

With unity of aim came diversity of method; the scientific investigator devoted himself mainly to the study of molecular problems, while the industrial worker applied his energies to dealing with iron and steel in the mass. This division of labour and unity of purpose is well maintained, and it will be my object to show how beneficial it has been and still is. At every great stage of our progress the industrial worker had an investigator of pure science close at hand.

From the technical point of view, as the eighteenth century closed, a new era in the metallurgy of iron had already begun. Abraham Darby had successfully introduced the use of coke in the blast-furnace; James Watt had, by his powerful engines, much facilitated the production of blast, and had greatly stimulated the out-turn of pig iron. Nevertheless, the total annual production of pig iron in the year 1799 did not exceed some 150,000 tons. From the scientific point of view the situation was one of singular interest. The early writers held that good and bad qualities might be inherent in the iron itself. Pliny points out how greatly the properties of iron depend upon its

treatment, but he thought that as for the kinds of iron, they were many and all were distinct, and the first difference arises from the diversity of the soil and climate where the mines are found. But Pliny's view survived far into the present century, and evidence of it lingered in the effective and graceful speech in which the Member for Merthyr proposed a vote of thanks to our first President on the delivery of his inaugural address. Mr. Fothergill said then that "thirty years ago the idea prevailed universally . . . that good iron was to be found in certain localities, and could be procured from no other place; it was found good in one place and bad in another." He adds: "Enlightened progress of the last thirty years has shown that the quality of iron depends upon the alloy with which it is mixed."

Enduring as the old view as to the influence of locality was, an experimental basis for a more accurate one had been established very shortly before the present century began, and some, at least, knew that the properties of iron depended on the presence or absence of certain other elements. This position was clearly established by the great Swedish chemist, Bergman of Upsala, who had shown that carbon is the element to which steel and cast iron owe their distinctive properties. He had initiated the employment of calorimetric methods in determining the properties of iron and steel. He insisted that the real difficulty is to explain how it is that the presence of 0·5 per cent. of carbon in iron enables the metal to be hardened by quenching from a red heat, or, in his own expressive words, *Ceterum quomodo dimidia centesima, plumbaginem efficiens, tantam provocare possit differentiam, nodus est gordius haud facile solvendus*. Bergman, moreover, anticipated the later phases of modern research by claiming that iron is a polymorphic element, and plays the part of many metals. In this early view as to the allotropy of iron it should be remembered that in 1790 our countryman, James Keir, followed him closely by urging, before the Royal Society, that what we now call passive iron "is really a distinct form of iron, the alteration being produced without the least diminution of its metallic splendour or change of colour."

Clouet's celebrated experiment on the carburisation of iron by the diamond followed. Doubts, however, were not finally set at rest until 1815, when Pepys, a working cutler in London,

excluded the possibility of the intervention of furnace gas. But, as soon as the present century had well turned, the industrial world was in possession of the fundamental fact that carbon is the element of dominant importance in relation to the metallurgy of iron. Well might Bergman express astonishment at the action of carbon on iron. Startling as the statement may seem, the destinies of England throughout the century, and especially during the latter half of it, have been mainly influenced by the use of steel. Her steel rails seldom contain more than Bergman's half per cent. of carbon. Her ship-plates, on which her strength as a maritime power depends, contain less than half that amount. It is essential that the significance of this fact should be clearly understood. Our national existence has long depended on iron and steel. They have been the source of our wealth, one of the main elements of our strength, one cause of our maritime supremacy. Hardly a step of our progress or an incident of our civilisation has not, in one way or another, been influenced by the properties of iron or steel. It is remarkable that these properties have been determined by the relations subsisting between a mass of iron, itself protean in its nature, and the few tenths per cent. of carbon it contains. These properties are, it is true, modified either by the simultaneous presence of elements other than carbon, or by the thermal or mechanical treatment of the mass. The growth of our knowledge of the facts constitutes a large section of our scientific and industrial history. The question arises—Was our national progress delayed by the unreadiness of the technical world in England to take advantage of the facts that science had established?

If we consider the position from the point of view of two remarkable men who were looking for the dawn of the nineteenth century as we are for that of the twentieth, we shall, I think, be satisfied that our progress received no check from failure of industrial workers to assimilate the teaching of science. These men were Black and Cort. Of the scientific men then living, the greatest chemist was Black, Professor at the University of Edinburgh, whom Lavoisier had generously acknowledged as his master. Black fully recognised the importance of Bergman's work, and on his own part insisted on the importance of what would

now be called the change in molecular energy as the physical basis on which the properties of iron and steel depend. Black, moreover, in his public lectures gave a singularly accurate description of the process of decarburising iron called "puddling," and devised by "a Mr. Cort," with the results of whose work Black was soon to become familiar. Considering how recent the knowledge of the meaning of oxidation really was at the time, Black's statements with regard to the theory of puddling are truly remarkable. Later on he furnished the Government with an elaborate report on the quality of the material obtained by puddling. He showed, by such mechanical tests as the experience of the time suggested, the superiority of puddled iron, and pointed out that it was more suitable than foreign iron for the appliances "on which," as he says, "the lives of our seamen and the safety of our ships have hitherto mainly depended."

At the end of the century we are justly proud of our Colonial possessions, and are satisfied that the varied applications of iron and steel will enable us to knit together all parts of the Empire. At the beginning of the century, Lord Sheffield in his "Observations on the Commerce of the American States," writing in the early days of Cort's process, shows that it would help to make British iron as cheap as the foreign, an event which he considered would be more advantageous to England than the possession of her American colonies. Black died in 1799,

1799. Cort survived till 1800, so that as the eighteenth century closed, the most eminent scientific man and the foremost practical metallurgist of the generation stood side by side. To Cort we owe the greatest technical advance the modern world had seen; to Black the recognition of the importance of molecular energy in relation to metallurgical problems.

The production of pig iron in this country also received a great stimulus from the discovery by Mushet about the year 1800, that the large deposits of blackband ironstone could be utilised. The century opened with, in round numbers, an annual production of pig iron not exceeding 200,000 tons, of which less than one-third was converted into bars and other descriptions of wrought iron. The capital invested was under five millions, and employment was furnished for nearly 200,000 people.

Returning to the scientific aspect disclosed at the dawn of the century, the year 1803 was an eventful one for science. Nevertheless the impulse given to research was not in the **1803.** most favourable direction for the advancement of metallurgic art. The influence of a small proportion of carbon on iron had been recognised, but the quantitative relation between the iron and the carbon was only considered as bearing on the nature of the product, and not at all from the point of view of chemical union. When, therefore, in 1803, Claude Louis Berthollet published his *Essai de Statique Chimique*, it appeared that the action, of what for the moment I may be permitted to classify as the action of *traces* upon *masses*, was in a fair way to be elucidated for the following reason. Berthollet pointed out that "in comparing the action of bodies on each other which depends on their affinities and mutual proportions, the influence of mass has to be considered." Unfortunately in succeeding years the views of Prout, the courteous opponent of Berthollet, prevailed, mainly through the powerful aid of Dalton, who published also in 1803 his first table of atomic weights. Hence the phenomena which could not be attributed to fixed atomic proportions were set aside and usually neglected. Evidently the action of one-tenth per cent. of carbon on iron could not be explained by the aid of combining weights. The century was more than half over before a school of eminent chemists arose, who did not insist that matter is minutely granular, but in all cases of change of state made calculations on the basis of work done, viewing internal energy as a quantity which should reappear when the system returns to its initial state.

The production of cast iron and bar iron was rapidly increasing, and the suitability of cast iron and bar iron for the construction of bridges became evident to engineers, among whom Telford was pre-eminent. A distinguished professor, a worker in **1802-7.** pure science, came, in the person of Dr. Thomas Young, to the aid of the technical worker. The need of studying the mechanical properties of iron and steel was evident, and Young showed that the work done in permanently extending or in compressing iron or steel could be represented by a co-efficient, to which he gave the name of the "Modulus of Elasticity." This co-efficient has probably rendered more service in the

development of the study of the strength of iron and steel than any other which has been determined. It is of great importance, because upon it depends the deflection which a structure will take under strain. Young, evidently with a view to bring home evidence as to the great rigidity of steel, gives in his original paper a quaint illustration. He therein shows that if "Hook's law holds" a hanging rod of steel would have to be 1500 miles long in order that the upper portions of it might be stretched to twice their original length. I would incidentally point out that on the basis of Young's calculation, such a column 1500 miles high, if it were 1 foot $2\frac{4}{5}$ inches in diameter, would represent the output for the past year of Bessemer steel in this country alone. Statements of this kind had such a singular fascination for Sir Henry, that I have permitted myself a brief departure from chronological order in offering a new one.

In the year 1817 the patent was granted to the Rev. Robert Stirling, the specifications of which showed that he
1817. had a clear conception of the "regenerative principle," which, applied to furnaces, as will be shown later, has been so fruitful in connection with the manufacture of steel.

In the year 1818, Samuel Baldwin Rogers substituted "iron bottoms" for the sand ones which had been introduced by Cort
1818. in the puddling-furnace. I find in the work on "Iron Metallurgy" by Rogers, published in 1857 (but apparently embodying much information he had promulgated in 1818), the statement that his "principal aim" in proposing the use of iron bottoms for puddling-furnaces was "to work the iron in a bath of cinder." He also suggested the use of a flux of a very basic character, and he adds the interesting statement that use of "the proposed flux will rapidly remove the metalloids from the iron." He pointed out that "the metalloids were removed in the shape of oxides, and combined with the cinder in the puddling-furnace." The actual result was to greatly improve the quality of British iron, and therefore Rogers deserves recognition, which has hardly been accorded to him, as a pioneer of the great basic process of dephosphorisation.

Between the years 1800-4 the amount of foreign iron annually imported was 40,200 tons, and one consequence of the improved

method of puddling was to greatly diminish the importations, which in the period 1823 to 1830 fell to 17,015 tons a year.

In the year 1820 malleable iron began to replace wood for the manufacture of colliery rails, mainly through the efforts of Birkenshaw.

The first quarter of the century did not draw to an uneventful close, for Faraday, working with Stodart, an eminently practical man, gave (in 1820) a stimulus to the study of alloys, and produced the first specimen of nickel steel. In a letter to De la Rive dated April 20, 1820, Faraday writes: "Mr. Stodart and myself have been engaged in a long series of experiments and trials on steel, with the hope of improving it, and I think we shall in some degree succeed." Later on he writes: "If you knew the labour of the experiments you would applaud us for our perseverance at least."

In the year 1822 Faraday pointed to a fundamental difference between hard and soft steel, the latter yielding a "carburet of iron" when treated with hydrochloric acid, while hardened steel dissolves completely.

Early in the second quarter of the century notable progress was made, for on the 3rd of March 1828, James Beaumont Neilson enrolled his patent for the application of the hot-blast to furnaces. It has been suggested by two of my predecessors in this chair that the introduction of the hot-blast might be characterised as a "lucky hit." Viewing, however, the merits of Neilson's great invention in relation to general metallurgical progress, it will be evident that exception may be taken to this suggestion. Neilson's contemporary, David Mushet, held that the introduction of the hot-blast "marked one of the grandest epochs in the history of the manufacture of iron," and he urged that the discovery was the more remarkable as being opposed to received opinions and prejudices, "it being universally held that the blast should be kept as cold as possible." Neilson was an enthusiastic student in Anderson's College, Glasgow, and his strenuous advocacy of technical instruction proved him to be singularly in advance of his age; he was also an ardent experimenter. Moreover, he clearly says he was led to think that "if air was increased in volume by heat, it might be enabled to do more duty." In a sense he was right,

for the expansion of the air, though perhaps it was not so important as he thought, represents one-third of the energy contributed by the intervention of the hot-blast stove. That his invention owed anything to "luck" was evidently not the opinion of our own Royal Society, of which body he was elected a Fellow in 1846, as the discoverer of the "hot-blast system of manufacturing iron," and as being "distinguished for his acquaintance with the science of mechanical philosophy." The practical results of the hot-blast were marked, and in the ten years which followed the introduction of his invention the production of pig iron in this country was more than doubled. The history of the period is singularly interesting.

Nasmyth's patent of June 9, 1842, embodies the first drawing of the perfected single-acting steam-hammer. Such hammers had been proposed by James Watt in 1784, and sketched by Deverell in nearly its present form in 1806.

At this time a great investigator appeared in the person of Dr. Thomas Andrews of Belfast, the application of whose great work on the heat of combination will be referred to later.

It is perhaps natural that in the rest of the first half of the century the most noteworthy feature seems to be the renewed attention devoted to the investigation of the nature of oxidation and reduction. As the investigations, which were of great importance, were mainly conducted on the Continent, I must reluctantly leave their consideration until a future meeting. In the blast-furnace there was evidently a kind of tidal ebb and flow in the relations of carbon and of oxygen, resulting sometimes in reduction, and at others in oxidation or carburisation; but the changes were all capable of more or less simple expression if viewed either from the atomic or the dynamic standpoint. As the furnaces grew in dimensions, their flaming tops threw a lurid glare over the country, and, "like the dying sunset kindled through a cleft," revealed the magnitude of the problems involved in blast-furnace practice, which were seen to be disproportionate to their apparent simplicity.

As regards the study of the nature of the ascending gaseous column, I may anticipate the remarks I shall have to make next year by pointing out that the labours of the illustrious chemist

Bunsen were shared by the late Lord Playfair, and that a joint communication of theirs was published in the Report of the British Association for the year 1846.

In the first half of the century efforts were directed mainly to obtaining a material—cast iron containing some $3\frac{1}{2}$ per cent. of carbon, and fusible at a temperature readily attained in the blast-furnace. In the second half of the century, while efforts to obtain this fusible material were increased, attention was also directed to removing the carbon, and obtaining a product which had a melting-point of 400° C. (720° F.) higher than cast iron. This product was either cast directly into ingot moulds or recarburised to the extent necessary to constitute the various gradations of steel. Sheffield hardly knew steel except as a material to be used for the manufacture of cutlery, for which she had been famous since the time of Chaucer.

It is characteristic of our British methods that special circumstances and needs, mainly arising in connection with the development of the steam-engine and railways, revealed the broad principles by which the production of iron must be governed. It was natural, therefore, as time went on, that in the work of successive inventors the guidance of scientific principles became progressively evident as ill-directed efforts were gradually replaced by the results of systematic experiments.

The second half of the century began with an event of strange importance; for in 1851 the Great Exhibition revealed our industrial strength to all nations. The official reporter of the 1850–51. Metallurgical group states that 2,250,000 tons of pig iron were annually produced in this country, and that its estimated value was £5,400,000. The annual production had risen in fifty years from two hundred thousand tons to over two and a quarter millions. Sheffield produced at the opening of the century 35,000 tons of steel, of which 18,000 tons were cast steel. Messrs. Turton exhibited a single ingot of steel weighing 2688 lbs., but Krupp showed an ingot of double the weight, for our country was only preparing for the great change which was so soon to enable it to lead the steel manufacture of the world.

A noteworthy feature of the Exhibition was the collection of iron ores of this country exhibited by Mr. Blackwell, who subsequently, and most generously, provided funds for their analysis.

With reference to this collection, the reporter points out that in this country "the ores are not carried far, except where there is great facility for transport." This is noteworthy, as before the century was much older an important supply of ore was brought from Spain, and in the near future we may even seek a supply for British furnaces from distant parts of our own Empire.

The year 1851 was, moreover, an important one for metallurgy in this country, as it saw, by the wisdom of H.R.H. the Prince Consort, the establishment of the Institution which developed into the Royal School of Mines. If the projected scheme of instruction had been fully carried out, the provision of a general system of technical instruction, which the pressure of necessity is slowly forcing upon us, would have been anticipated by forty years.

In the year of the Great Exhibition the blast-furnaces seldom exceeded fifty feet in height, and it was not until 1864 that Mr. John Vaughan erected a furnace seventy-five feet high, with remarkable results as regards increased output; since then the gigantic furnaces of the Cleveland district have become common.

The year 1856 will be ever memorable in the metallurgical annals of our nation as that in which Bessemer gave the description of his process to the world at the Cheltenham
1856.

Meeting of the British Association. As regards the process itself, we have too lately lost our great countryman, and many of us are too familiar with the details of his labours to be able either to fully estimate its value or to realise the wonder of its results. Let us try to think of the Bessemer process as I believe those at the end of the twentieth century will, whose views must range over a wider perspective than we can command. The economic aspect of the question will naturally strike the metallurgists of the twentieth century. They will see that in 1855 the make of steel in Great Britain did not exceed 50,000 tons, and the cost of the steel produced sometimes reached £75 a ton. They will see that thirty years after the publication of Bessemer's patent the production of Bessemer steel rose to 1,570,000 tons, and that ship plates were sold at £6, 10s. a ton. It will be noted that before the century closed, the maximum production of Bessemer steel in this country in one year reached 2,140,000 tons. The scientific aspect of the process will, how-

ever, excite their widespread interest, for before the end of the twentieth century, metallurgy will be taught in our older universities. It will be seen that, notwithstanding the title of Bessemer's Cheltenham paper, he recognised and insisted on the fact that the intense heat was engendered by the combustion of the elements within the fluid bath. It will be noted in what close relation the purely scientific work of Thomas Andrews of Belfast, on the heat of combination, stands to that of Bessemer, and that another instance is presented of the dependence of industrial work on pure investigation. Bessemer's proposal to employ a mixture of steam and air will not be ridiculed as it has been, for speculation will be rife as to whether he did not hope that the liberated hydrogen might remove sulphur and phosphorus, notwithstanding the feebly exothermic result of the ensuing combination, and in spite of the cooling effect of water vapour. In view of the fact that endothermic combinations take place at a high temperature, the possible action of hydrogen as a decarburiser will be dwelt upon. Professor Noel Hartley's papers upon the Thermo-Chemistry of the Bessemer process will be read with much interest. Surprise will, however, be widely felt that physicists generally of the last half of the nineteenth century did not see in the lovely flames of lilac, amethyst, gold, and russet, or in the "stars suspended in a flying sphere of turbulent light" which come from the converter, an appeal to fully investigate their cause and to study the dynamic problems presented by the intense heat engendered. Why was not the destination ascertained of the 1000 cubic feet of argon which accompanies the air passing through the metal during an ordinary Bessemer 10-ton blow? Why were not more strenuous efforts made to ascertain the effect of the temperature of the bath on the nature of the metal? Was not an attempt made to ascertain whether the iron itself, and any of the known elements it contained, were truly decomposed by the intense heat?

It will be felt that, as the eighteenth century had closed with a clear statement as to the true nature of oxidation, the nineteenth century had seen its magnificent application in the Bessemer process.

As regards the work of Mushet, future generations will, I believe, desire to add nothing to the words of the President

of this Institution who, in 1875, had the pleasure of awarding the Bessemer Medal to him. Mr. Menelaus then said "that the application of spiegeleisen . . . was one of the most elegant as it certainly was one of the most useful inventions ever made in the whole history of metallurgy."

Attention must now be directed to the great process for the production of steel which involved the use of the
1861. "open hearth."

Sir William Siemens' life was one long and ultimately brilliantly successful effort to apply the kinetic theory of gases and the dynamical theory of heat to industrial practice. He was eminently a practical worker; but the depth and accuracy of his scientific knowledge gives him a place near that of all the great atomists from the time of Lucretius to that of our own countrymen, Graham, Joule, Clerk Maxwell, and Kelvin. In many of Siemens' papers, theory and practice are closely blended. In viewing the results of his labours, it will be seen in future ages that confidence in the trustworthy character of steel was finally established by experiments on metal produced in the regenerative furnace of Siemens. Looking back, it is astonishing with what difficulties the use of steel for structural purposes was beset. In 1859 Sir John Hawkshaw was not permitted by the regulations of the Board of Trade to employ steel in the construction of the Charing Cross bridge. Time will not permit me to indicate the efforts which were made to induce the Board of Trade to remove the serious hindrances to the use of steel, which had "rendered the construction of the projected bridge over the Firth of Forth practically impossible." These efforts were not successful until 1877, when a committee, consisting of Sir John Hawkshaw, Colonel Yolland, and Mr. W. H. Barlow, were able to recommend that the employment of steel in engineering structures should be authorised by the Board of Trade. The steel employed was to be "cast steel, or steel made by some process of fusion, subsequently rolled or hammered;" one condition of such recommendation being that "the greatest load which can be brought upon the bridge or structure, added to the weight of the superstructure, should not produce a greater strain in any part than $6\frac{1}{2}$ tons per square inch."

As regards the use of steel for shipbuilding purposes, in

the year 1875, Sir Nathaniel Barnaby asked, "What are our prospects of obtaining a material which we can use without such delicate manipulation, and so much fear and trembling?" He partly answered his own question four years later, when he quoted experimental evidence as to "the recent successes" of open-hearth steel. In 1890 he completed the case by pointing out that naval architects now "have a perfectly regular material, stronger and more ductile than iron," and he speaks of "our lasting debt of gratitude for the birth and training of that true prince, William Siemens." It is hardly necessary to point out that the country owes the excellent materials used in naval architecture mainly to the productions of the regenerative furnace.

In connection with the production of mild steel, the addition of ferro-manganese to the decarburised bath proved to be most effective. We can hardly over-estimate our indebtedness to those whose perseverance ensured the adoption of mild steel for maritime and other purposes. "Looked at from the standpoint of to-day, when thousands of tons of such steel are made weekly without serious anxiety or trouble, it is scarcely possible to realise the anxieties and difficulties of the days when the manufacture of open-hearth steel was being perfected." To no one is our debt greater than to our Vice-President, Mr. James Riley, who bore a large share of the anxieties of the early days, and whose words are those I have just quoted.

With regard to the great modifications which have been effected in the Bessemer and open-hearth processes, reference must be made to that ample source of information, our Journal. It must also be consulted for the history of the appliances for heating the blast with which the names of Cowper and of Whitwell will always be specially connected.

In speaking of Bessemer and Siemens I have been obliged to depart somewhat from strict chronological order. I must now resume it at the year 1865.

Sir Joseph Whitworth patented on November 24, 1865, a process for submitting liquid steel to heavy pressure, at the critical juncture when the metal is passing from the fluid to the semi-fluid state, to prevent any part of the casting from becoming hollow or unsound.

In the year 1866 Graham's first paper on the occlusion of gases by metals was published in the *Philosophical Transactions*. Its results have been far-reaching, and will always rank with the metallurgical triumphs of the century.

In the year 1869 our Institute was founded. In view of certain aspects of the treatment which inventors had previously received from their industrial brethren and from the country, it will be evident that the time for its formation had fully come. Taking instances almost at random, I may remind you that Dud Dudley was, as he says, "with lawsuits and riots wearied and disabled" in the seventeenth century, and that Henry Cort was neglected and oppressed in the eighteenth. The great invention of iron bottoms in the puddling-furnace made by Rogers was received with ridicule, and he died in poverty. Popular tradition of Sheffield indicates that possession was obtained of Huntsman's secret "by the heartless trick of a rival." Neilson, though he warmly acknowledges the support he received from certain ironmasters, was treated with singular meanness by others. Heath fought single-handed for fifteen years "against a common purse, the accumulation of the wealth which he had created." Even Bessemer's early statements were received with incredulity and contempt. With the formation of our Institute all this is changed: men place the results of their work and experience freely at the disposal of their brethren, and each fresh advance meets with appreciative consideration. "Vigorous moderateness," wrote the late Walter Bagehot, "is the rule of a polity which works by discussion. . . . It was government by discussion that broke the bond of ages and set free the originality of mankind."

The history of our industry since the formation of this Institute is epitomised by the labours of those who have hitherto occupied the Presidential chair. The DUKE of DEVONSHIRE, K.G., our first President, worthily sustained the honour of the name of Cavendish, one of the most illustrious in the scientific annals of our country, and the connection of the Duke with the iron industry of Barrow is an incident of the first importance in our industrial records. He highly appreciated the importance of science in relation to the progress of the nation ;

and the Report of the Royal Commission on Scientific Instruction, of which he was President, contributed in no small degree to the awakening of public attention to the subject. His noble foundation of the Cavendish Laboratory at the University of Cambridge stimulated research on lines closely connected with this Institute, as the work of Clerk Maxwell, of Rayleigh, of J. J. Thomson, of Ewing, and of Heycock and Neville, abundantly testify. It is certain that the main efforts of his life were directed to developing the resources and improving the condition of the people. Neither rank, wealth, nor intellectual gifts had power to affect the simplicity of his character or to lessen the deep sense of duty which controlled all his actions.

The life-work of our second President, Sir HENRY BESSEMER, has already been dealt with, and the lesson it teaches is how **1871-73.** vastly important the labours of one man may be to a nation. In these days the facilities for work are much greater than they were, and results are obtained by an army of workers; but, as Stanley Jevons has pointed out, the influence of the individual genius is "not withering, but is growing with the extent of the material resources which are at his command." It was during the Presidency of Sir H. Bessemer that Snelus patented the use of basic lining for furnaces and crucibles, which was ultimately found to be so important in relation to the elimination of phosphorus from pig iron.

Sir LOWTHIAN BELL embodies for us the progress in blast-furnace practice of at least the last half-century. It was under **1873-75.** his Presidency that the first Continental meeting was held, the place chosen being Liège, Belgium's great metallurgical centre. He was the author of the first paper communicated to the Institute, choosing as a subject "The Development of Heat and its Appropriation in the Blast Furnace." There is a passage in the Presidential address of Dr. Percy with reference to the work of Sir Lowthian Bell which I may be permitted to quote. Dr. Percy said: "His laborious, careful, and original investigations of scientific problems of the highest interest in the metallurgy of iron and steel must be so well known to this audience that any comment upon them from me would be superfluous, if not presumptuous." If Dr. Percy, the metallurgical historian of the age, thus shrank in 1885 from **1899.—i.**

the attempt to give adequate expression to the value of Sir Lowthian's work, it would be impertinent in me to say more than that the fourteen years which have passed since Dr. Percy wrote, have only served to bring into greater prominence Sir Lowthian's unswerving devotion to the solution of those problems he has so patiently studied.

Attempts to improve the ancient operation of puddling by the aid of mechanical appliances, received their fullest development

1875-77. under the guidance of WILLIAM MENELAUS. The great

usefulness of his career may perhaps be well indicated by the statement that he was among the first to be convinced of the vast superiority of steel to puddled iron, and urged its adoption with singular foresight and vigour. His position as manager of Dowlais Works gave great force to his advocacy. By lending his great mechanical resources and power of organisation to scientific research, he brought about some of the greatest improvements that were ever effected in the iron and steel industries. He associated himself, moreover, with Edward Riley, who, as an analytical chemist, subsequently made a distinguished name.

The work of Sir WILLIAM SIEMENS has already been dealt with as fully as time will permit. I will, therefore, only quote the

1877-79. public tribute to his memory which was offered at the

time of his death in 1883: "The nation at large has lost a faithful servant, chief among those who live only to better the life of their fellow-men by subduing the forces of Nature to their use. Looking back along the line of England's scientific worthies, there are few who have served the people better than this, her adopted son—few, if any, whose life's record will show so long a list of useful labours."

EDWARD WILLIAMS shares with Menelaus the unique distinction of having been the first to appreciate the great importance of

1879-81. Bessemer's discovery, and within three days after the

publication of Bessemer's paper at the British Association he erected at the Dowlais Works a small fixed converter, had blown pig iron, and had rolled the product into bars, "to the great astonishment of all concerned." His vigorous address as President of this Institute was remarkable for the then prophetic expression of belief, that the day was "at hand when either by a Bessemer

converter or by the open-hearth . . . there will be produced with absolute certainty, with comparatively light labour, and (he hoped) with fair profit to all concerned, every kind, variation, and quality of the metal iron which we rudely designate steel and wrought iron." He also made a striking appeal to educated intellectual young men who "hung listlessly" about the professions "to break through the absurd old prejudice against seemingly rough work, and come over to the healthy business of iron and steel-making, in which they might render the world good service."

JOSIAH TIMMIS SMITH, in his Presidential address, gave a remarkable retrospect of the period which had elapsed since the foundation of the Institute. He showed that, comparing the year 1880 with the year 1869, 2½ millions more tons of iron had been made with the same amount of fuel, or we had, in fact, economised our fuel supplies to the extent of 10,000,000 tons. He gives a masterly summary of the progress in our industries, and eloquently pleaded that chemistry had proved its claims to be regarded as the handmaid of the iron manufacturer, and had given our metallurgical art a place in relation to the exact sciences which it could never otherwise have occupied. He also urged with great force that our Institute had broken down the spirit of exclusiveness and prejudice, that is usually the most rampant where knowledge is most wanting.

To Sir BERNHARD SAMUELSON is due the credit of being the first to succeed in convincing the House of Commons of the national importance of Technical Education in its widest sense, and to induce it to grant a Select Committee to inquire into the provisions for giving instruction in theoretical and applied science to the industrial classes. I wish I knew which of his wise and careful utterances he would like me to quote. Left to my own choice, I reject reference to his elaborate array of statistics, and select the following brief passage from his Presidential address: "It is to the further development of the world's railways that we must mainly look in the future as in the past for the support of our trade." Bearing in mind what is happening in Egypt, in South Africa, in China, and on the frontiers of our Indian Empire, the vast importance of railways, to which Sir Bernhard refers, cannot be doubted.

Hence the engineer, considered as a pioneer, is absolutely dependent for steel rails and for the material for the construction of bridges on the metallurgist, whose work is the real foundation of progress. One other sentence, which is typical of the whole tenor of his life's work, may be quoted: "It is in the mutual co-operation (in a scientific spirit) of every grade in our great craft that we may build up the hope, nay, that we may cherish the certain expectation, of placing it on even a higher eminence than that which it has already attained."

In no other branch of modern scientific literature than that of metallurgy does one individual stand far above his contemporaries and absolutely dominate his subject as does **1885-87.** Dr. JOHN PERCY. It may be fairly claimed that he did this, for he truly represents the progress of metallurgical literature during the nineteenth century. He was also the century's greatest teacher; he found metallurgy practised in this country as an empirical art. His splendid works contain a record of its progress; his lectures at the Royal School of Mines secured it a scientific basis, and he trained a body of workers in whose hands the immediate future of metallurgy still, to a great extent, rests. To few men does the nation owe more than to our President of 1885-87. The educational work Dr. Percy began is being actively developed. As regards its progress in the future—which is of vital importance—there seem to me to be no requirements that may not be abundantly met by the extension of existing institutions. The establishment of a Board of Mining and Metallurgy in connection with the new Teaching University for London, would, I am satisfied, greatly stimulate instruction in these subjects.

DANIEL ADAMSON will be known rather as a mechanical engineer, and the originator of the Manchester Ship Canal, than as a metallurgist. His Presidency of this Institute **1887-89.** is, however, remarkable for his strenuous advocacy of the use, not only of steel as distinguished from iron, but that for definite purposes steel of a definite degree of carburisation and suitable composition should be employed. He also eloquently urged that the steel at all stages of its manufacture in its varied applications should receive suitable thermal treatment. He strongly advocated the use of steel for the manufacture of boilers,

and he pointed out that by the use of steel rails and weldless solid rolled steel tires the saving to railway shareholders amounted to about £3,120,000 sterling per annum, while the safety and security of the travelling public had been correspondingly increased. No better indication of progress in the decade ending 1889 could well be given than this.

The vast advance during the century in the applications of iron and steel in the manufacture of machinery, and more especially to locomotives, is fittingly represented by **1889-91.** Sir JAMES KITSON. We, moreover, owe him a deep debt of gratitude for the admirable way in which he represented the Institute by presiding at the Autumn Meeting which was held in Paris in 1889, as well as during the arduous but most remarkable visit to the United States in 1890. Sir James, by his unflagging vigour and unfailing tact, did much to cement the friendship of workers in iron and steel both among our neighbours in France and our kinsmen in America. I will only add that he has persistently advocated the use, and has well maintained the reputation, of that admirable material, "best Yorkshire iron."

One of the most noteworthy events in the metallurgical progress of this country was the acceptance by Sir FREDERICK ABEL of the post of Chemist of the War Department. The **1891-93.** teaching of such illustrious men as Berzelius, Heinrich Rose, and Liebig was just in process of thorough application in this country when Abel left our matchless teacher Hofmann to take his place among the earliest trained analytical chemists whose aid was sought by the ironmaster. He thus became, as it were, the "Patron" of works chemists. They are men on whose patient, monotonous, and often inadequately recompensed, labours the quality of British iron and steel has in no small measure depended, and I am glad to have this opportunity for offering my brethren, the chemists in works, a respectful tribute of admiration. The magnitude of their work may be gathered from the fact stated in the Journal of our Institute that in one basic steel works over 110,000 determinations are made in a single year by three chemists and six assistants. Of Sir Frederick's numerous investigations, the one which appeals to us most closely is that which definitely settled, as Fe_3C , the composition of carbide of iron.

Lord Herbert of Lea, who was several times Secretary for War, and was in office soon after Sir Frederick was appointed to Woolwich, appears to have been advised that "steel was wholly inapplicable for the manufacture of ordnance." When we consider what the nature of our present war material is, and reflect how large a part Abel played in its introduction and adoption, it will be evident that any further comments of mine as to the value of his labours would be unnecessary. He is himself a most active exponent of the truth "that the intimate blending of science with practice lies at the root of all industrial progress and success."

I am quoting from an American source the testimony that "an historical sketch of the perfecting of modern processes of steel manufacture would afford the best glimpse that 1893-95. could be given of the career of EDWARD WINDSOR RICHARDS." He was among the first to appreciate the need for reversing mill engines, and an early one erected by him is still at work at Ebbw Vale. He designed the works of Messrs. Bolekow, Vaughan & Co. at Middlesbrough, the largest in the kingdom, and as general manager of the famous Low Moor Works has fully maintained its reputation for the production of one of the most famous varieties of iron in the world. His connection with what is known as the basic process will be alluded to later on. In view of the fact that appliances will handle and forging presses deal with weights of steel up to 100 tons, he long ago anticipated the possibility of making 10 tons of steel into one ingot.

The progress of an industry during the century can only be adequately indicated by the evidence afforded by statistics. In this respect no more comprehensive statements could 1895-97. have been desired than those embodied in the Presidential address of Sir DAVID DALE. Sir David has, however, secured a firmer claim to the gratitude of the nation than that which is derived from his powers as a statistician. He has from time to time been the trusted arbitrator between masters and men, and as Chairman of one section of the Labour Commission (1891-94), rendered admirable services in the interests both of capital and labour. He was also the representative of this country at the Berlin Labour Congress

of 1890. His work has, moreover, enabled us to trace in the last twenty years of the century, the progress of the spirit of equity among all sorts and conditions of men, who have gladly borne testimony alike to his firmness and his justice. His efforts have been unwearingly directed to removing difficulties which have from time to time arisen between employers and the employed. I need hardly allude to his long services as Treasurer of this Institute, nor do you need to be reminded that we owe the ability to carry on our work efficiently to his careful husbanding of our resources.

To the foresight of EDWARD PRITCHARD MARTIN we owe the adoption in practice of one of the great processes which will render the nineteenth century memorable. I refer to what is collectively called the "Basic process." It would be impossible to trace its history now. I prefer in any reference, which must of necessity be so brief, to appeal to the appreciative words in the paper which Sidney Thomas and Percy Gilchrist communicated to our Institute in 1879. They then stated that, "on laying some of the first results obtained from this six-pound converter before Mr. Martin of Blaenavon, he at once recognised their importance, and from that time we have been deeply indebted to him for his unfailing and consistent support and much valuable advice and assistance." It need only be added that the metallurgical world is also under a lasting debt of gratitude to Mr. Martin. Later on other aid was as gracefully recognised. Mr. Thomas said, on the occasion of his receiving the Bessemer Medal (1883), "the present position of dephosphorisation has only been rendered possible by the frank, generous, and unreserved co-operation of Mr. Windsor Richards, and of our earlier and consistent supporter Mr. Martin." All those I have named have received the Bessemer Medal. We lost Sidney Thomas far too soon. Mr. Snelus, to whose work I have already referred, and Mr. Gilchrist received the highest honour the scientific world has to bestow—the Fellowship of the Royal Society.

The introduction of labour-saving machinery in the great Dowlais Works, which Mr. Martin directs, marks an era in British metallurgy.

This concludes the list of those who have hitherto presided

over this Institute, and it will have been evident that from time to time other interests than those connected with iron and steel have been represented by your Presidents. We were reminded of this fact when the Institute first met, now twenty-four years ago, at Manchester, where we are promised a delightful meeting again next autumn. The Bishop of that great city then welcomed us by a quotation from Virgil, which connects the age of iron with the age of gold. The passage runs thus:—

*“quo ferrea primum
Desinet ac toto surget gens aurea mundo.”*

A President of this Institute who has had the privilege to serve in the Mint in a sense connects the iron and the golden age. I find that during the course of a long official career I have been responsible for the standard fineness of over one hundred and twenty-one millions of gold coin. This sum is so vast, and the anxiety connected with it has been at times so great, that I am not careful to conceal the pride revealed by this reference to it, as it is an exponent of the financial greatness of the nation which created the age of steel. But I value as highly the means of conducting research and the hope of being useful, which was also given me by the Government when I was appointed Professor of Metallurgy at the Royal School of Mines. I have in the discharge of my duties persistently striven to show that what is called applied science is nothing but the application of pure science to particular classes of problems.

I regret that space will not permit me to consider the progress of the century as measured by the work of our Bessemer Medalists. I hope, however, as regards the labours of the foreign recipients of the honour, to deal with them next spring. The metallurgy of America is so closely interwoven with our own, that I must permit myself a brief reference to four men who stand out from the industrial ranks of our kinsmen. These are Alexander Lyman Holley, the Hon. Abram S. Hewitt, John Fritz, and Professor Henry Marion Howe, all of whom are Bessemer Medallists.

I only once had the good fortune to see the winsome pioneer of the Bessemer process in America, “our dear Holley,” if I may borrow and adopt the phrase used to me by one of the American

members at Stockholm last autumn, with reference to one the charm of whose character was neither impaired by difficulty or by success. All Holley did for the Bessemer process is fully recorded in our Journal, and it is only necessary to state, that from the time the first charge was blown at the Troy Works in 1865, there have been produced in America over sixty-one million tons of Bessemer steel.

It was in the works of the Hon. Abram S. Hewitt that the first Bessemer converter was installed, and Mr. Hewitt was also the first to build an open-hearth furnace in the United States.

Mr. John Fritz was one of the small band of leaders who so successfully developed the Bessemer process in the United States, and excited the admiration of the metallurgical world by large outputs from comparatively small installations. He also aided in designing one of the most important arsenals in the world, where the highest quality of open-hearth steel was produced.

Of the labours of my friend, Professor Henry Marion Howe, it would be difficult to speak adequately. As an experimental investigator he has greatly added to our knowledge of the properties of iron and steel. In the field of literature he has left on record a monumental work which enables him to rank with Dr. Percy as the metallurgical historian of the Anglo-Saxon race.

It may help us to estimate the value of the labours of the four men whose names I have given if we remember that at the present time the United States export about a million tons of iron and steel a year, while twenty years ago they were not exporting any. We may fairly consider, therefore, their influence on the rapid development of the United States navy. It would seem that we, in this country, in the belief in our insular security, had somewhat neglected the art of naval warfare, until Admiral Mahan reminded us of what we had done in the past, and of our possible course in the future, in a series of writings which have done much to convince the two nations, England and America, "that they are in many ways one."

It is time to offer a collective statement of the achievements which have either been actually effected or are in immediate prospect.

There are blast-furnaces which will produce 690 tons of pig iron in twenty-four hours, with a consumption of little over 15·4

cwts. of coke per ton of iron. The gases from blast-furnaces are used not only as sources of heat, but directly in gas-engines.

There are Bessemer converters which can hold 50 tons of metal, and open-hearth furnaces which will also take 50 tons, while 100-ton furnaces are projected. The open-hearth furnaces are fed with one ton of material in a minute, by the aid of a large spoon worked by an electro-motor. There are gigantic "mixers," capable of holding 200 tons of pig iron, in which, moreover, a certain amount of preliminary purification is effected.

Steel plates are rolled of over 300 feet in area and 2 inches thick. There are girders which justify the belief of Sir Benjamin Baker, that a bridge connecting England and France could be built over the Channel in half-mile spans. There are ship-plates which buckle up during a collision, but remain water-tight.

There are steel armour piercing shot which will penetrate a thickness of steel equivalent to over 37 inches of wrought iron. The points of the shot remain intact, although the striking velocities are nearly 2800 feet a second. There are wires which will sustain a load of 170 tons per square inch without fracture. Hadfield, whose labours will, I trust, be continued far into the twentieth century, has given us manganese-steel that will not soften by annealing; while Guillaume has studied the properties of certain nickel-steels that will not expand by heat, and others that contract when heated and expand when cooled. Nickel, chromium, titanium, and tungsten are freely used alloyed with iron, and the use of vanadium, uranium, molybdenum, and even glucinium, is suggested. There are steel rails which will remain in use seventeen years, and only lose 5 lbs. per yard, though fifty and a half million tons of traffic have passed over them.


Huge ingots are placed in soaking pits and forged direct by 120-ton hammers, or pressed into shape by 14,000-ton presses. With such machinery the name of our late Member of Council, Benjamin Walker, will always be connected.

There are steel castings for parts of ships that weigh over 35 tons. We electrically rivet and electrically anneal hardened ship-plates that could not otherwise be drilled. Photomicrography, originated by Sorby in 1864, now enables us to study the pathology of steel, and to suggest remedial measures for its treatment. Stead's work in this field is already recognised as

classical. Ewing and Rosenhain have, in a beautiful research, recognised quite recently by its aid, that the plasticity of a metal is due to "slip" along the cleavage planes of crystals. Osmond also, as an incident in a magnificent series of researches, shows that the entire structure of certain alloys may be changed by heating to so low a temperature as 225°C .

Passing to questions bearing upon molecular activity, we are still confronted with the marvel that a few tenths per cent. of carbon is the main factor in determining the properties of steel. We are, therefore, still repeating the question, "How does the carbon act?" which was raised by Bergman at the end of the eighteenth century. Nevertheless, from the molecular point of view, much may be said in answer to the question. The mystery is in fact lessened now, as it is known that the mode of existence of carbon in iron follows the laws of ordinary saline solutions. Our knowledge is, however, of very recent origin, and we owe mainly to the Alloys Research Committee of the Institution of Mechanical Engineers the development of Matthiessen's view that there is absolute parallelism of the solution of salt in water and carbon in iron.

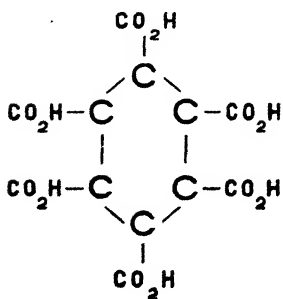
An ice-floe in a Polar sea contains a small percentage of salt; a red-hot ingot of mild steel holds some two-tenths per cent. of carbon, but both the carbon and the salt are in the state of *solid* solution. If the ice had been cooled below -18°C ., it would entangle a solidified portion of salt water, which was the last part of the mass to remain fluid. So in the steel ingot, when it has cooled to the ordinary temperature, there is a solidified "mother liquor" of carburised iron. We do not as yet know whether carbon is dissolved in fluid iron as carbon or as a carbide. We do know, however, that the presence of 0.5 per cent. of carbon in iron (such an amount as might occur in a steel rail) lowers the melting-point of the iron from 1600°C . to 1530°C . This lowering has enabled a calculation to be made, the result of which shows that the number of atoms in a molecule of carbon in *fluid* iron at this temperature is probably *two*. It can be shown that at a temperature of 800°C . the number of atoms in the molecule of carbon dissolved in *solid* iron is, in all probability, *three*. At lower temperatures the number of atoms is probably more than three. We metallurgists are not accustomed

to think in atoms. Let me, therefore, represent such a three-atom molecule thus,  without assuming how much iron is

associated with the carbon. Following Bergman's experimental method, but with the interval of more than a century separating his work from ours, we investigate the action of acids on carburised iron with a view to ascertain the nature of the atomic grouping of the carbon.

In explaining this, I may adopt the appended figure. It is most difficult even to attempt to make questions of atomic grouping clear in a paragraph, but the figure will be helpful. To the historian it suggests vivid pages of Italian history, as the six spheres so arranged constitute the arms of the powerful family of Medici. To the chemist it is a precious symbol, and appeals to him as representing the carbon atoms as grouped in the benzene ring. The result of treating carburised iron with various acids is the formation of marsh-gas and more complicated organic compounds, of which propylene, acetylene, ethylene, and naphtha may be mentioned. Does the nature of these products help us to ascertain the number of the atoms in the carbon molecule as it exists in cold steel? I have consulted organic chemists, among whom I would specially mention my colleague, Dr. Wynne, and their evidence is encouraging. The result of the action of powerful

oxidising agents on certain forms of carbon is mellitic acid, $C_6(CO_2H)_6$, which is one of the benzene series, and this favours the view that solid carbon contains twelve, or some multiple of twelve, atoms in the molecule. But mellitic acid is graphically represented in the annexed diagram, the carbon atoms being arranged as the six spheres are in the arms of the Medici. The group CO_2H is tacked on to each carbon sphere. From this it may be argued that the molecule of solid carbon consists of one or more carbon "rings." In



cold steel the group of CO_2H may be replaced by the group Fe_3 , which is broken off by the action of suitable solvents leaving free carbon. Hence the six-atom carbon molecule may exist in steel.

My object is merely to show you how far at the end of the century we have advanced in our knowledge of the mode of action of carbon, and I trust it will be evident that the progress is remarkable. We know that even in solid iron the carbon atom must push and thrust with great vigour, for we can measure the "osmotic pressure" the carbon atom exerts, and, as has just been shown, we can even picture the mode of the atomic grouping in the molecule.

I can only just sum up the evidence as to the occurrence of molecular change in iron. To Gore, and to Barrett, we owe the investigation of the nature of a fact not unknown to smiths, that iron on cooling from a bright red heat suddenly emits a glow. We now know that as steel cools down there may be at least six points at which molecular change occurs, accompanied by evolution of heat.

In a series of classical papers of which we are justly proud, for many of them have been communicated to this Institute, our member, Osmond, has shown what is the significance of these points, and has won an enduring reputation. We measure and record them photographically as readily as if they were barometric variations. It is known that six molecular changes occur in the purest electro-iron yet prepared, one of which is connected with the magnetic permeability of iron, while two points, which occur far below a red heat, appear to be due to the presence of hydrogen. In steel one point, at least, is due to the power iron has of dissolving carbon. Moreover, the molecular condition of steel cooled from an intense white heat is not the same as that of steel which has just been melted. To carry further the evidence as to the effect of an intense heat on iron in a vacuum is the task I have in prospect during my Presidency of the Institute. I may, however, express my agreement with Lockyer's view that the evidence afforded by the atmosphere of the stars shows that our terrestrial iron is a very complex form of matter.

We must not lose sight of those relations of carbon and iron

which involve physical equilibrium. Even the astonishing associations of iron and carbonic oxide in the volatile gaseous compound with which the distinguished name of Mond is connected, affords a triumph of dynamic chemistry. It is generally supposed that ozone is dissociated at 160° C., but Dewar has devised a beautiful experiment to prove that ozone has two centres of stability, and one of these is near the melting-point of platinum. It seems to be the same with the relation of hydrogen and iron. We have recently learned that iron and hydrogen appear to be completely dissociated at 800° C., and yet the same iron heated to some higher temperature, say 1200° C., will still yield hydrogen.

Let us suppose that Black, Cort, and Bergman were with us again, and had reviewed the present state of our knowledge and the work accomplished in the century. Let us also suppose that they could go to Sheffield and see an armour-plate rolled and finished for service, and then, visiting our Institute, hear the best explanation we could offer of all the incidental phenomena they had witnessed. Which would they consider the more advanced, our practice or our theory? They would probably hesitate to tell us, but would offer warm congratulations on the immediate prospect of the establishment of a National Physical Laboratory, in which investigations as to the properties of iron and steel will be continued.

The relations subsisting between capital and labour are of vast importance to our industry, and it would not be justifiable to omit reference to them. There is, indeed, abundant precedent for the discussion of this subject in the Presidential addresses of Mr. Windsor Richards and Sir David Dale.

**Economic
Considerations.**

I venture to hope that the next generation will look back with astonishment to the deplorable aspects presented by what is known as the labour question at the close of the nineteenth century. It is only natural that British enterprise should be met by foreign competition, and I will not dwell on the evidence of our shortcomings in adapting ourselves to the requirements of foreign trade afforded by "our shaming Consular Reports." They are serious enough, but as regards the workmen, their demands for increased wages and reduced hours of work, and, what is far

more serious, for the right to determine how little shall be done in those hours, entirely ignore the conditions under which other nations are competing with us. The situation last year was even perilous, for twelve unfinished warships bear eloquent testimony "to the great, though fortunately not irretrievable, misfortunes primarily traceable to the recent engineering dispute."

The multiplied strikes of the last few years have deprived the country of the great advantage it formerly possessed, both as regards excellence of work and punctuality of delivery. To take only the last coal strike; the indictment against the men was thus tersely expressed in *The Times*: "The men lost some £3,000,000 in wages; they crippled the coal trade; they stopped the naval manœuvres; they spread misery broadcast in the district; and they played into the hands of the non-associated owners, who realised large profits, of which but a very small portion found its way into the pockets of the workmen." Capital and labour, which ought to be in amicable association, are too often antagonistic. It may be urged that the antagonism is but a struggle, and that the fittest and strongest must survive, and that we are powerless in the presence of the working of a natural law. Formerly some of us might have been disposed to accept this as inevitable. But my late distinguished colleague, Huxley, in the Romanes Lecture delivered by him at Oxford in 1893, recognised that there are two opposing methods at work in the government of the world. These are respectively the *ethical* and the *cosmic*. The practice of that which is ethically best involves a course of conduct which in all respects is opposed to that which leads to success in the cosmic struggle for existence. "In place of ruthless self-assertion, it demands self-restraint; in place of thrusting aside or treading down all competition, it requires that the individual shall not merely respect, but shall help his fellows; its influence is directed not so much to the survival of the fittest, as to the fitting of as many as possible to survive." Thus Huxley, one of the most acute thinkers of the century, has placed sympathy on a scientific basis by suggesting • to us that, in the complex problems which the labour question presents, the ethical method must not be lost sight of; no effort to provide for the well-being of the industrial population can be too persistently adopted. Strangely enough in giving advice

to workmen at this critical time, when, as the result of labour conflicts, trade has been lost to the country, we can appeal directly to their self-interest, and in this case industrial influence will be more effective than ethical ones. It is, moreover through economic means and industrial influences that mankind tends to grow together, and it may confidently be anticipated that the workmen's self-interest, if only it can be rightly directed, will effect the changes in the relation between capital and labour which the moral sense of the men has been unable to accomplish. The highest ethical teaching of true leaders like David Dale, "will then find their late echo in the assent of the multitude."

"Within the trade union movement," write Mr. and Mrs. Sidney Webb in their very interesting work on "The Industrial Democracy," "we find the collectivist-minded working-man grounding his regulation of the conditions of employment upon what we have called the doctrine of a living wage." What that wage should be is most difficult to define; but is there an employer who hears me who is not anxious that each of his people should earn a "living wage," or who feels that the conditions of the life of labourers in the Black Country, as pictured by Charles Dickens in the forties, disgraced humanity? How could people who dwelt under such conditions respect themselves?

How can the legitimate self-interests of the workmen be rightly directed? We must hope that the inclusion of the teaching of economic subjects in the scheme of primary education will do much. We must hope that Boards of arbitration and conciliation will have immediate effect, and will find their full fruition with the rising generation, who may be expected to be more firmly disciplined and to have a higher sense of duty than their fathers. We must trust that frequent discussions between employers and the employed will enable mutual interests to be clearly seen. We must learn that the warmest sympathy with the workmen's rights is not inconsistent, in face of common dangers, with stern and vigorous treatment of labour difficulties which threaten the national prosperity.

Let us hope that advantage will be taken of the prevailing prosperity to place these questions on a satisfactory basis.

It will have been evident how great a share our country has had in forming the age of steel. The range of properties steel possesses is wide, and by its use the energies of a multitude of workers have been, as it were, concentrated in a few great efforts which have exerted vast influence on the progress of humanity. Men with most varied aims have, by the use of steel, been enabled to reveal their genius. Especially is this true of the Members of the great Institution of Civil Engineers, whose hospitality is so generously extended to us. The forces of Nature have been utilised through the intervention of machinery, which could not have been constructed if steel had not been known. By the adoption of steel distance has been abridged, and it has been possible to express our national attributes of courage and endurance in concrete forms. You who produce steel have enabled the designer of the greatest fleet ever seen to claim that our nation has "become the ship-builders of the world."

As a plastic material steel has served as a vehicle for embodying the imagination of the Art Worker. To the Chemist and Physicist steel presents complex problems for research, and affords boundless hope that further changes in its composition or treatment will enable new wonders to be wrought which will make the future a rich inheritance.

At the end of the century we are hoping that a Royal Charter will be granted to our Institute, the members of which have, as I have shown, done so much. That the well-being of the nation depends on its scientific and industrial progress, was recognised in the charter given to that centre of all scientific advance, the Royal Society, in 1662, by His Majesty King Charles II. In this charter the King said: "We have long and fully resolved with Ourselves to extend not only the boundaries of the Empire, but also the very arts and sciences." The method by which this was to be effected had been suggested long before by the better-known words of another monarch, who wrote the proverb: "It is the glory of God to conceal a thing, but the honour of kings is to search out a matter." Industrial or scientific truths are hidden, but we have freedom of search by "actual experiment." The humblest investigators of the properties of iron and steel may, therefore, make the resolve of

Charles II. and share the glory of Solomon ; for, bringing our intellectual gifts into closer union with our practical interests, and broadening the boundaries of the metallurgic art, will assuredly enable us to make better use of our existing possessions, and will lead to the extension of the Empire.

Sir BERNHARD SAMUELSON, Bart., Past-President, said he was about to inaugurate the President's reign by an act of rebellion, for, without asking the President's permission, which his modesty might perhaps have induced him to refuse, he was about to propose that the most hearty thanks be accorded to the President, Sir William Roberts-Austen, for his address, and that he be asked to permit it to be printed in the Journal of the Institute. Whilst perpetrating this act of rebellion he was sure that he was only doing that which would have the approval of the meeting. No one could have heard the address which had been just delivered to them without appreciating its eminent qualities ; but before he commented on it in a very few words, he would venture to say that when their excellent President brought to their knowledge the fact that Her Most Gracious Majesty had condescended to accept the Bessemer Medal of the Institute, he omitted to remind them, as he might have done with advantage, that one of the first acts of Her Majesty after the arduous labours connected with the ceremony of the Jubilee, was to proceed to Sheffield to take part there in the rolling of an armour-plate for one of our ships of war to form part of the navy, which, he hoped they might safely say, commanded the seas. They expected great things from the address of their President, but he had seemed purposely to make his task difficult by having subjected it to comparison with those of his predecessors. He would venture to say that those who succeeded him, when they came to analyse that address and present an epitome of it such as the President himself had given of those of his predecessors, would say that by that comparison it suffered in no degree. If he were to criticise it, he would say that its characteristics were boldness, elegance, and felicity of expression. In regard to the latter

he would only call attention to the art with which the President had pictured to them one of the most abstruse facts of science by the exhibition of the six balls of the arms of the Medici, which must recall to them so many pleasant suggestions, especially to those of them who were in the habit of visiting Italy. Then he would give another instance of the art which he had shown in the composition of his address, that was in the picture of the garden from which he contemplated the commencements of the great iron industry of this country, for whilst he called attention to the discovery which had recently been made of coal in the southern counties of England, he had been careful not to disturb their minds by any suggestion that that discovery might possibly revolutionise the iron trade at a time when they were just emerging from a period of suffering which he hoped had now entirely ceased. He might give many other instances of what he might almost call the wonderful literary talent which their friend had exhibited in his address. With respect to its more solid qualities, its weight and importance as an epitome of the progress which had been made in this country in the craft upon which their fortunes depended, and which the President fairly and properly held in such high estimation, it was not necessary that he should dwell. That was what they all expected from him. They also expected the qualities of felicity of expression and literary skill; but he believed that when this address came to be compared with those of his predecessors, it would be in the latter respects that it would be found to be peculiarly remarkable. It would hold an eminent place in their publications, and he was sure that, repeating the words of the resolution which he had to propose, the most hearty thanks would be accorded to the President, Sir William Roberts-Austen, for his address, which they asked him to permit to be printed in the Journal of the Institute. In proposing that resolution he was sure he would have the sympathy of every one present.

* Sir WILLIAM H. WHITE, K.C.B., said that, in the absence of the President of the Institution of Civil Engineers (who was unfortunately and unexpectedly prevented from being present by an official engagement), he, as one of the Vice-Presidents

of that Institution, would ask the meeting to permit him to second the resolution of Sir Bernhard Samuelson. He could not do it as a member of the Iron and Steel Institute, because that was an honour which he did not enjoy; but he desired to do it, not merely as a Vice-President of the Institution of Civil Engineers, but also as one of the representatives of those professions which benefited largely by the work of this Institute. Users of the materials which the members of this Institute produced necessarily watched with the greatest interest all improvements that were made. Speaking for himself, he would say that for thirty years he had taken the most earnest interest in the progress of the manufacture of iron and steel. From the proceedings of this Institute one was able to gather not merely valuable information as to accomplished facts, but as to possibilities and tendencies. Perhaps he might be allowed to say one word for the part which the users of these materials had taken with regard to improvements in manufacture. They had heard to-day in the Presidential address of the introduction of mild steel for shipbuilding. That was a work in which his friend and former chief, Sir Nathaniel Barnaby, had played a great part, while he himself had the honour, as a much younger man, of assisting. But he ventured to recall to the members of the Institute that shipbuilders were not offered that material; they had to ask for it. While he recognised most fully the work which had been done by the steelmakers of this country in meeting demands, and while he heartily endorsed what their President had so well said as to the work done by Mr. James Riley in particular, yet he would venture to assert that the introduction of mild steel, and its great developments in recent years, were largely influenced by the action of users of that material. He did not think it was for users to go behind the details of manufacture. He had said in that room, not many evenings ago, that there were some engineers who were disposed to trench upon the province of the steelmakers. But users of materials had an undoubted right to insist upon mechanical and working qualities they desired to obtain, and not to be happy till they got them. The keynote of the President's address, in which they had all been most thoroughly interested, and which they would read in its full expansion with the greatest

pleasure, was the part which scientific investigation had played and must play in industrial progress. No one could doubt that that principle was the true one. Might he venture here to say that he did not think that in all cases the principle was applied as fully as it might be in the great manufactories of this country? Perhaps that might not be a popular statement to make, but it was his conviction that in other countries more was being done by what he would call "private research" than was being done universally—he would not say there were not exceptions—in this country. He would suggest for the consideration of iron and steel makers present, as one who took the most hearty interest in the welfare of that great industry, that it was possible for them to work farther on those lines. Passing by that suggestion, they all agreed with the principle that the President had laid down, that scientific investigation was the basis of modern industrial progress; and they all rejoiced that the principle was applied in other departments besides metallurgy. He thought the President himself had made one great omission; he had not referred to his own work. But speaking in another capacity, as President of the Institution of Mechanical Engineers, he wished to say that what Sir William Roberts-Austen had done in connection with their Alloys Research Committee represented work which, standing alone, must secure for him the respect and admiration of all those who were interested in the subject. It had been suggested that while the President had dwelt upon the arms of the Medici as representing the molecular structure of steel, he somewhat slurred over his other diagram showing three instead of six spheres. This diagram also represented the arms of another ancient family, although in modern times they had been put to baser uses, and were to be seen suspended from certain shops in some of our own streets. These diagrams might at present be considered as somewhat speculative representations of modes of combination between the constituents of steel, but the endeavours which Sir William Roberts-Austen and other members of the Institute were making to analyse the internal structure of steel and other metals had already led to considerable practical results, and would undoubtedly lead to yet more remarkable results. Watching as he did the armour-plate manufacture of this country and abroad, he could say that the

recent advances that had been made in consequence of scientific research were most notable and most suggestive. He trusted that Sir William Roberts-Austen would continue to devote himself to this remarkable and suggestive investigation, until at least the time when the National Physical Laboratory, of which he had spoken, should take it over, and do for the country in a State-aided institution what Sir William Roberts-Austen, with the help of the Institution of Mechanical Engineers, had been endeavouring to do for some years past.

Sir BERNHARD SAMUELSON said he would not repeat the words of the resolution, but would ask the meeting to pass the resolution in the most hearty manner.

The PRESIDENT said that he was very grateful to Sir Bernhard Samuelson and to Sir William White for the exceedingly kind—the far too kind—words in which they had proposed and seconded the resolution. He was glad to think that he had a term of office before him which could not fail to be pleasant to him, and he would certainly spare no effort to make it useful to the Institute. With regard to the hint of Sir Bernhard Samuelson that he had not mentioned the fact that Her Majesty, as the first official act of her Jubilee, had seen at Sheffield the armour-plate for the *Ocean* rolled, he did not think it desirable to allude to the incident again, as it had already occupied a prominent place in a lecture which he had delivered in Canada immediately after that historical event. With regard to Sir William White, and his most appreciative reference to the work conducted by the Research Committee of Mechanical Engineers, he thought he ought to say that the fact that it had been carried on so successfully was due to the permission he had had to direct the work in the Mint laboratory, which permission had been accorded to him by his friend, Sir Charles Fremantle, and by the present Deputy-Master of the Mint, Mr. Horace Seymour, to whom he and those present had abundant occasion to be grateful.

The following paper was then read :—

THE GELLIVARE IRON ORE MINES.

By H. BAUERMAN, F.G.S.

THE mineral region known as Gellivare * Malmberget or Ore Mountain is situated in 67° 11' North latitude and 20° 11' East longitude, near the headwaters of the Lina, one of the western tributaries of the Kalix River, at a distance of about 100 miles from the Gulf of Bothnia, in a hilly district, rising to about 2000 feet above the sea-level, which is, as a rule, fairly well covered with pine and birch wood, only the higher summits rising clear of the forest line. The natural drainage line is not, however, feasible for communication, and the approach is by a line of railway 132 miles long from Luleå, following a marshy plateau-country dividing the basins of the Luleå and Kalix Rivers. The line at Boden, 20 miles from Luleå, meets the Northern State Railway, giving a through communication with Stockholm, a distance of about 820 miles.

The character and distribution of the mineral deposits, which have formed the subject of several previous communications, are shown in the sketch map, Plate I., prepared from a plan kindly furnished by the general manager at Gellivare, Herr Disponent Bossæus, from which it will be seen that the mineral field contains a large number of lenticular masses, varying very considerably in size, and covering a space of about $3\frac{1}{2}$ miles in length by $1\frac{1}{2}$ mile in greatest breadth, which may, however, be grouped into two principal series. The most important of these, which is locally known as the Great Ore bed, *Stora malmen*, extends from Vålkommen on the west to Tingvalls Kulle on the east, in a V-shaped line, nearly following the ridge dividing the waters of the Vasari and Lina streams, which rises to a height of about 2000 feet at the western and 1900 feet at the eastern end, and falls in either direction towards the centre, about the Hermelin mine, which is at the point of the V. This line includes the more

* Formerly the Finnish name Gellivara was generally used, but this has now been abandoned for Gellivare, which is the Lapp rendering.

important mines, but the mineral ground extends in both directions, or about $\frac{3}{4}$ mile southward from Vålkommen on the so-called western district, *Vestra Området*, and south-east. for about $1\frac{1}{2}$ mile from Tingvalls Kulle to Koskulls Kulle, but these outlying districts have not as yet become the seats of active workings. The principal deposits of importance are in the Kaptenshöjden, and include the Kapten, Frederika, and Selet mines.

The structure of the ore masses is generally similar throughout the district. They are apparently bedded, following the direction of the foliation of the containing rock, and dipping southward at inclinations varying between 50 and 80 degrees. The prevailing rock is a red felspathose gneiss, finely foliated, with a very small proportion of mica and other dark minerals, which are at times completely absent, giving the so-called hälleflint gneiss. The principal accessory mineral is titanite, which occurs in minute crystals, but apatite is comparatively rare, the amount of phosphorus contained in a sample taken from about the centre of the district being only 0.04 per cent. Grey gneiss of variable texture and composition, containing dark-coloured mica and hornblende, is tolerably abundant, but usually in subordinate quantity to the red variety. Granite and pegmatite in veins of an intrusive character, varying from a few inches to several yards in thickness, are met with both in the gneiss and the ore beds, especially in the Kaptens' district. A curious example of the inclusion of lenticular masses of pegmatite in the ore exposed in the Josefina mine is shown in Plate II.*

The ore got in the mines is essentially magnetite, only a small quantity of a very hard specular hematite, breaking in rhombohedral fragments, being found in the large deposits of Tingvalls Kulle and Vålkommen. The magnetite has a peculiar granular structure, and is mostly very pure, in the sense of freedom from metallic sulphides and other waste minerals, the latter being confined to small inclusions of hornblende, mica, felspar, calcite, and corundum. Quartz is also found occasionally in the specular

* Reproduced, as well as Plates V., VI., and VII., from photographs by Mr. H. McNeill, Assoc. M. Inst. C.E. Plates III. and IV. are from photographs by Melander, of Gellivare.

hæmatite. The characteristic associate of both minerals is, however, apatite, which is almost universally present, although in very variable quantity. It generally appears in rounded or somewhat elongated granules, interspersed through or alternately when in larger quantity with the magnetite, in bands varying from a mere line to an inch or two in thickness, which are usually colourless or pale green in tint. In the hollow of the pegmatite veins well-defined crystals are occasionally found; they are of the yellowish-green variety known as asparagus stone. One of these crystals, from a pegmatite vein in Vålkommen, after being carefully freed from associated rutile and titanite inclusion, was found to be of the following composition:—

| | | |
|---|---|-------|
| Insoluble in acid | 0.28 | |
| CaO | 55.20 | |
| FeO | 0.24 | |
| P ₂ O ₅ | 41.81 = Ca ₃ P ₂ O ₈ | 91.25 |
| Cl | 0.19 = CaCl ₂ | 30 |
| Fl | 3.67 = CaFl ₂ | 7.52 |
| | <hr/> | |
| | 101.39 | 99.07 |
| Less O corresponding to Cl and Fl | 1.54 | |
| | <hr/> | |
| | 99.83 | |
| Sp. gr. | 3.213 | |

The apatite from Kiirunavaara is almost identical in composition, containing chlorine 0.22, lime 55.00, and P₂O₅ 41.51 per cent.

The most detailed observations that have been made upon the distribution of apatite in the Gellivare ores are those of Mr. Hjalmar Lundbohm, contained in the reports of the Royal Swedish Commission * on the occurrence of apatite in Norbotten, which investigated the subject in 1890 and 1891. From these it appears that the most abundant development was in a trial pit at the western end of the Johan mine, where a breadth of 8 feet of mineral exposed was made up of sixty alternations of magnetite and apatite, the bands of the purer mineral varying from 0.2 to 12 inches, and of the latter from 0.125 to 32 inches in breadth, the whole section giving 28 per cent. by volume or 19 per cent. by weight of apatite, corresponding to 3.5 per cent. of phosphorus (fluor apatite contains an average of 42.4 per cent. P₂O₅, or 18.5 per cent. P). The purest ores are found in

* *Sveriger Geologiska Undersökning Afhandlingar*, Ser. C., No. 111, 1890, and N 127, 1892.

the Kaptens and Koskull districts, where the range in apatite is from 0·06 to 2·02 per cent. Outside of the ore region proper, north of Josefinä mine, masses of apatite of considerable size, with only a small admixture of magnetite, have been found in the pegmatite intrusions sometimes associated with fluor spar.

According to the Report of 1890,* which contains the earliest detailed investigation of the district, the total area of the more important ore deposits may be estimated at about 437,600 square metres, or 108 acres. Over about one-fifth of this area the ores contain 0·06 to 1·06 per cent. of apatite, or 0·011 to 0·196 per cent. phosphorus; those with 0·152 to 0·85, or averaging 0·382 to 0·495 per cent. phosphorus (2·06 to 2·67 per cent. apatite), occupy about one-tenth, while in the remaining seven-tenths the phosphorus varies from 0·185 to 4·05 per cent. (1 to 21·9 per cent. of apatite), with a general average of more than 0·5 per cent. The experience of actual working has, however, led to a reduction in the estimated area, which is now given at about 200,000 square metres (49 acres).†

The difference in colour and density between the two principal minerals allows, however, of a very complete separation of the purer from the more phosphoric ores, being made by hand-picking alone, and it is found possible to classify the output into five different qualities, as follows:—

| | | | | | |
|---|---|---|-------|---|-----------|
| Class A with 67-70 per cent. iron and 0·01-0·05 phosphorus. | | | | | |
| " | B | " | 66-69 | " | 0·05-0·10 |
| " | C | " | 65-67 | " | 0·10-0·80 |
| " | D | " | 63-65 | " | 0·70-1·50 |
| " | E | " | 57-61 | " | 1·50-3·00 |

As a rule, the higher qualities are more compact than those at the lower end of the scale, which break up readily owing to the loose texture of the apatite.

Up to the present time the working has been carried on almost entirely in open cast, the ore broken in the quarries opened at the summit of the hills being lowered by self-acting inclined planes to the branch railways connecting with the Malmberget-Gellivare line. The longest of these branches on the eastern side serves the Vulkan and Tingvalls Kulle district, following a

* Lundbohm, No. 111, p. 47.

† Nordenström, *Journal of the Iron and Steel Institute*, vol. liv. p. 43.

circuitous course for about $3\frac{1}{2}$ miles to the foot of the inclines on the northern slopes, which is about 370 feet below the summit of the hill. A shorter branch on the western side extends to the inclines from the Johan Välkommen and Linné group, which are laid on the southern slope. The more centrally-placed mines have their outlets by inclines leading directly to the Malmberget station, that from the Josefina and Upland group with its branches being nearly a mile long. These inclines are laid on the surface of the ground as single lines, with three rails, and crossing-places for the return trucks, and are protected by snow sheds at the ends and in other exposed places.

The largest working, known as the King Oscar mine, on Tingvalls Kulle, is shown in its present state in the view on Plate III. This was opened about six years since, in a large mass of magnetite, having a total length of about 650 feet and a variable breadth of 25 to 230 feet dipping southwards, at a slope of about 50 degrees, and is now about 120 feet below the surface at the deepest point, the ground being worked downwards in terraces of about 50 feet in height. The ore broken in the faces is dropped through a shaft to a level, called the King Oscar tunnel, driving the rock on the foot-wall side through to the head of the incline. The mineral below this point will ultimately be worked by stoping above a deep level driven in from the end of the railway.

The adjoining mine to the westward, Sofia, is also of considerable size, and is worked at two levels, 50 feet apart, in a mass of rather phosphoric ore, about 1500 feet long and 150 to 200 broad, which crosses the Kunssryggan near its highest point. The outlet is, however, by an incline about half a mile long to the Tingvalls Kulle branch railway. Nearly one-half of the present output is derived from the workings in this group.

The mines in the Kaptenshöjden district, including Hertigen af Östergötland, Kapten, and Frederika, which form a connected group about three-quarters of a mile in length, and the smaller deposit of Selet, about 600 yards farther north, and produce the purest mineral, have attained the greatest depth, and in several points are below the level of the railway. These are now in process of development by shafts sunk on the hanging wall side to a depth of about 170 feet, which will be equipped with electric

winding engines. Plate IV. represents the lowest working of one of this group, the Frederika mine.

The most important arrangement for future systematic development of deep workings is, however, that known as the Hermelin tunnel, a large cross-cut, $18\frac{1}{2}$ feet broad and 10 feet high, starting from a point about half a mile east of the main-line station, and going north for 1400 feet, when it cuts the Hermelin deposits 100 feet broad. The section is sufficient to admit of three lines of way taking trams of $3\frac{1}{2}$ tons capacity; two of these are laid, and worked by an electric locomotive, hauling trains of six loaded trams. This level is in process of extension at the same height, but reduced in breadth to $13\frac{1}{2}$ feet both eastward and westward along the course of the great ore bed, and will ultimately form the principal outlet of all the northern deposits, which will be cut at considerable depth. The ore is broken in all cases by hand-boring and blasting with strong dynamite, masses too large to be handled being subsequently divided by smaller shots. The classification is done at the face, each class being sent away and loaded from a separate hutch in the shaft. The mining goes on continuously throughout the twenty-four hours, the miners working in eight hours' shifts, electric lighting being used during the night hours, which, however, are comparatively short during the most active working season. Incandescent lighting is used permanently in the Hermelin tunnel and other underground workings.

The whole of the power used in the mines is obtained from electric motors, which, together with the lighting and the heating of some of the buildings, are supplied with current from a central station, which has already been described in the *Journal of the Institute*, vol. liv. p. 283. The position of the station is shown on the map, Plate I., as well as the very extensive system of distributing leads, which have a total development of about six miles.

From the mouth of the Hermelin tunnel the railway is carried on a timber trestle work over the main line to a screening house, the arrangements of which have been fully described in vol. liv. p. 282, where the smalls are sifted out, and the larger lumps are classified for loading into the main-line waggons. These are hopper-shaped, with two discharging spouts in the

bottom, built of steel plates, with six wheels on parallel axles, and fitted with air-brakes, about 9 tons weight empty, and carrying twenty-five tons. Each waggon is sampled before leaving, so that in the event of a question arising as to the classification of its contents it may be re-examined at the Luleå laboratory before shipment. The character of these trains is shown in Plate V., taken at the loading sidings at the foot of the Välkonnen incline. The loaded waggons are despatched at regular intervals to the main-line yard at Gellivare town station, where they are made up into trains of twenty-five to thirty-two, representing net loads of 625 to 800 tons, or 850 to 1024 tons gross, exclusive of engines and brake vans. Two engines are required, as there is a small intermediate valley to be crossed, that of the Rane-elf, before the line reaches the Luleå River on the way down.

The shipping station is situated at Svärto, on a rocky headland about $1\frac{1}{2}$ mile from Luleå town station, on the east side of the bay, where the material brought down during the winter is stored in large piles, and reloaded for shipment either by hand or by a steam-navvy. The loaded waggons are raised by a hydraulic lift carrying a lattice-hung platform with overhanging ends, carrying three waggons, which are brought successively opposite the loading shoots, and discharged through the hoppers in the bottom. The empty waggon is drawn by a chain haulage along the top of the gantry to a drop at the other end, where it is lowered to the ground. The lifting power is furnished by a 120 horse-power pumping engine by Messrs. Eastons & Anderson, supplying water to two 10-inch rams at 560 lbs. pressure to the square inch. This original loading arrangement being only suited to comparatively small vessels, a new loading stage has been erected farther down the harbour. This is a high built timber trestle, carrying a railway rising at 1 in 50, up which the waggons are drawn by locomotives, and are discharged by counterbalanced shoots leading directly into the steamer's hold. The general arrangements of this station are shown in Plate VI. The hydraulic lift and drop is seen on the right, and part of the high-level pier on the left.

Only the ores of the classes A to D are shipped, the E class and the smalls obtained by sifting being treated in the new separating works on the top of the hill, lying to the eastward of

the shipping wharf, and about 140 feet above it. The mixed material to be treated is lifted in side-tipping waggons by an inclined plane 130 feet high, and passes through a system of rock breakers, crushing rolls, and drying cylinders, which reduce it to particles of one millimetre maximum size for the magnetic (Ball & Norton's Monarch) separator, where the bulk of the magnetite is removed, yielding a product containing 70·5 per cent. of iron, a second intermediate product containing both magnetite and hæmatite assaying about 61 per cent., and a final non-magnetic portion consisting mainly of apatite, with some felspar mica and a little hæmatite. This is subjected to an elaborate system of sizing and washing, both by jigging and slime-dressing machines, in order to separate the iron-bearing mineral; the final product, consisting of all the lighter minerals, being subsequently converted into a material known as Wiborgh's Phosphate, which is a fertiliser analogous in composition to the slag of the basic Bessemer converter, a tetrabasic phosphate, but with one molecule of lime replaced by soda. At first attempts were made to produce quadribasic calcic phosphate from lime and apatite; but these proving unsuccessful, owing to the enormously high temperature required to effect combination, it was subsequently found that by using soda as the additional base the compound could be formed at a moderate heat, about 1000 degrees Centigrade. The finely divided apatite from the washing processes when dried in an Oxland calciner is carefully mixed with about 30 per cent. of sodium carbonate by trituration in a ball mill, and subjected to a fritting heat in a double-stage calciner, which converts it into a bluish-grey clinker or semi-vitrified mass. This, when cooled, is broken up and ground to a fine powder in ball mills in the same way as basic slag. The composition is as follows:—

| | |
|----------------------------------|----------------|
| P ₂ O ₅ | 27·01 per cent |
| SiO ₂ | 9·99 |
| SO ₃ | 0·27 |
| K ₂ O | 1·50 |
| Na ₂ O | 14·69 |
| CaO | 38·12 |
| MgO | 2·88 |
| Al ₂ O ₃ } | |
| Fe ₂ O ₃ } | 4·50 |
| FL and loss on ignition | 1·00 |
| | <hr/> 100·00 |

The proportion of phosphoric acid soluble in citric acid varies from 93 to 96 per cent., averaging 95, and increases with the proportion of soda to apatite in the mixture. The best results were obtained with 30 parts of soda to 100 of washed apatite, the latter containing about 17 per cent. of felspar, which contributes a portion of the alkali as well as the silica, the latter playing a notable part in the same way as in the basic slag.

From 20 to 22 cwts. of phosphate are produced from every 100 tons of ore passing through the separators. The present amount treated is about 200 tons daily.

A view of the magnetic separator house, showing the conical piles of separated minerals, is given in Plate VII. The left hand heap is magnetite, and that on the right hæmatite. As yet no very satisfactory outlet has been found for this material, in spite of their high contents of iron; probably its best use will be in the open-hearth furnace.

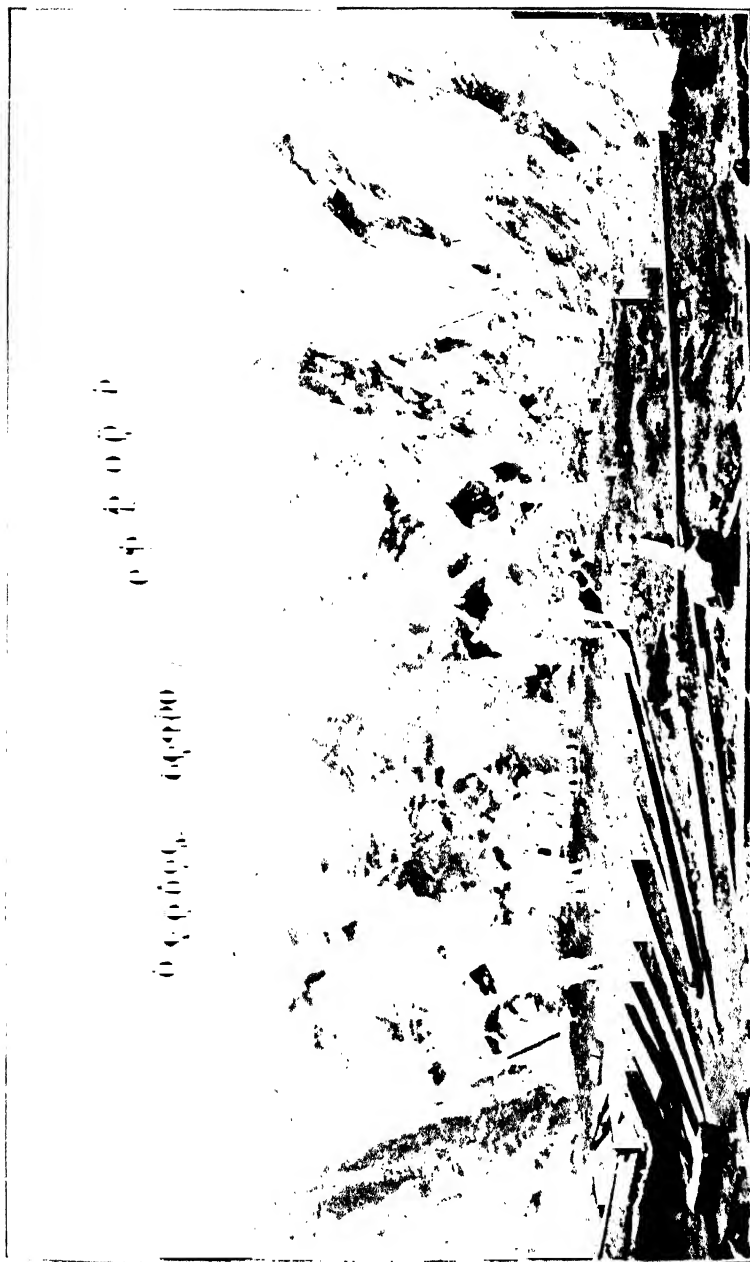
In concluding these remarks, it must be pointed out that they are to be regarded as mainly supplementary to the accounts given in the second volume of 1898, and as explanatory of the map and illustrations, which were, to some extent, necessary as completing the record of the extremely instructive and agreeable visit made to the mines last year.

DISCUSSION.

Mr. W. WHITWELL, Honorary Treasurer, did not think there was much to be said after hearing the excellent paper which had just been read, in addition to what had been said by him regarding their most interesting trip to Gellivare, and also Kiirunavaara and Luossavaara iron ore mines, at the meetings of the Iron and Steel Institute subsequently held at Stockholm. Those details had been published fully in the minutes of the proceedings of the Institute, and he did not think it wise for him to repeat what he had then said. He felt that they were exceedingly indebted to Professor Bauerman for his most interesting description of what he conceived to be the history of the past in reference to those mines. He would just say this, however, that as one who had used a very great quantity of that ore, he had found it absolutely necessary to pick over most carefully, and to select what was pure or what was only slightly impure from what contained a good deal more apatite than it was possible for them as practical ironmakers to deal with. It was exceedingly interesting to him to hear once again from Professor Bauerman what he had heard from him in discussion in previous papers, and those present were very much indebted to him for putting before them as clearly as he had done the very great interest that ought to be shown in the wondrous deposits of the wondrous district. It was pleasant to him to think that it was only one of a number of deposits in that part of the countries of Norway and Sweden; and as years went on they would doubtless see a great deal more of the ore worked. Whether it would be so good and so rich in iron as the best of the Gellivare ore, was perhaps very doubtful, but that it would be sufficiently good for making good hæmatite iron was clear. The coast of Norway also contained wondrous deposits of a more siliceous kind of ore than that in question, but eventually in the course of the next one or two years they might see what could be done for them. They in Cleveland were greedy; they saw the Spanish properties lessening the quantity of the purest ores, and certainly not improving in their



Pegmatite Inclusions in Magnetite, Josefina Mine



King Oscar Mine, Tingvallskulle



Lower Workings, Frederika Mine



Ore Loading Siding at Välkommen Incline



Svartö Shipping Station, Luleå Harbour

quality, this remark applying to the ores from Bilbao that are sent to England now. They were glad also to see the development of ore deposits which had taken place in South Spain; this was very welcome, as what was wanted by manufacturers really was to get a cheap trustworthy material, so as to enable them to supply a good and cheap pig iron for making steel. But still they wanted development; they wanted light and investigation, and they wanted to receive from other parts of the world that are not too far afield large quantities of ore brought over to help them in Cleveland. He felt that they had a very great business in hand in supplying the greedy steel producers, and they were only glad that any of their members should make investigations and show them new fields whence they could obtain what was absolutely necessary for the growth of that great industry in which many of them were so greatly and so deeply interested.

Mr. H. G. TURNER said that since he had had the pleasure of going to Sweden last year with many of his friends whom he saw present, he had paid a visit to Southern India, where, as they probably knew, there were very large deposits of magnetite of somewhat the same nature as existed in Sweden. These magnetite deposits had been known for many years—in fact, one of the earliest and most celebrated men connected with the development of steel was Josiah Marshall Heath, who belonged to the Madras Civil Service, to which he himself also belonged. In about the year 1820 Mr. Heath abandoned his career as a Madras civilian and went in for the study of the iron ores of Southern India. He thought that Sir Lowthian Bell had personal knowledge of Josiah Marshall Heath, and that he was well acquainted with the efforts he had made to introduce steel into Sheffield, and to other parts of England. These deposits in Southern India, although they had been written about and described in various journals, and in nearly every work on iron that could be read, from that of Dr. Percy downward, had for some years been neglected, and the reason why they had been neglected was not because they were inferior in quality in any way, or deficient in quantity, but because there was no fuel available to work them. The ores had

been smelted at various intervals up to about the year 1860 or later with charcoal, but gradually the forests got exhausted and the industry died out. It had occurred to many people to-day to see whether it was not possible to resuscitate the industry, either by the manufacture of pig iron in Madras, or perhaps in Calcutta, or by the concentration of the iron ore and by shipping it from Madras to be consumed in Europe. Of course the difficulty with regard to the shipping of the ore here was the question of freight. Whether that would be overcome or not was a matter still in doubt. He would not trouble them with any prophecies as to the future, but what he wished to tell them about was his visit there last January, in which he had seen the great mountain called Kanjamalai, where all these enormous deposits of magnetite existed. Last August he had been in Sweden, and there he had seen the deposits Kiirunavaara and Luossavaara and Gellivare, and he could assure them that the deposit of iron ore that he had seen in Kanjamalai far exceeded any individual deposit of ore that he had seen in Sweden, at any rate so far as the visible outcrops went. Of course they had not yet dived into the interior of the hill, and they could not say what was inside the hill, but so far as the outcrops went he was quite certain that so far as concerned the quantity, a larger quantity of ore existed in that individual deposit in Kanjamalai than in any deposit he had visited in Sweden. There are several other large deposits of iron ore in the neighbourhood of Kanjamalai. Then, coming to the question of the quality, so far as regarded the quality of the ore, they had before them the results of the investigations of Josiah Marshall Heath, and they knew that from the iron ore deposits in Southern India, of which that which he had visited himself was one, Josiah Marshall Heath produced most excellent steel or iron. He wished to tell them that that ore was the very ore that Josiah Marshall Heath used; in fact, he had been shown a house in which he lived at that time. He had with him Mr. Hugh McNeill, who was well known to a great many of those present, and who had spent more than a month there investigating the outcrops, and he (Mr. Turner) had a great many tests of the ore made by a chemist in India who was perfectly familiar with the art and practice of testing iron

ores. The results of the tests were such as to leave no doubt that in order to consider and understand the nature of this iron ore one must discriminate between ironstone and iron ore. The Government of Madras sent an engineer down there to investigate the ore, and this engineer had sent home a great quantity of ironstone, which when investigated by experts in England proved to be nothing more than an ironstone that contained about 38 per cent. of iron. The engineer in question seemed to have overlooked the obvious necessity of in some way cleaning the stone before he sent it home; and he (Mr. Turner) had no doubt that when Josiah Marshall Heath used the ore, he went through the very simple process of having it cleaned by the people of the country. That process was now in vogue at another place where the ore was concentrated by the simple process of crushing to a $\frac{1}{4}$ -inch size and then winnowing it. This concentration was carried on by nine women at a trifling expense, and as the silica and ore were easily separated, a very great improvement resulted in the percentage of iron. It had the effect of increasing the quality of the ore from about 30 per cent. up to about 50 per cent. Having seen this magnetic concentration going on in Sweden, he (the speaker) asked his chemist in India to submit the crushed iron ore to one of his horseshoe magnets, and he did so at his request, and he made a great many tests which he would read to them. What seemed to be typical of the results so far as they could be obtained was, that in the crude ore there was 38·65 per cent. of iron, of phosphorus 0·065, and there was no sulphur, differing from previous tests. This being concentrated, the analysis came out as follows: iron 51·85 per cent., phosphorus 0·058. In another sample in which the ore was crushed down to one-eighth of an inch, the result was that the iron came out 57·73, the phosphorus 0·045. He thought, as they were dealing with magnetite ore in Sweden, that the members present might take some interest in the condition of magnetite ore in Southern India. It was intended to send a couple of hundred tons of Indian ore to Sweden to ascertain its commercial value after treatment by magnetic concentration as practised in that country.

Sir LOWTHIAN BELL, Bart., Past-President, wished to say a word or two in reference to the allusion that Mr. Turner had made to himself. The individuals connected with the development of the iron trade mentioned in the magnificent and eloquent address of the President might be divided into two categories—those who had reaped renown and wealth, the other branch being those who might be considered the martyrs to the heavy undertaking they had endeavoured to carry out—and amongst those martyrs, of course, they had Dudley and Cort and Mushet, and he thought they must add to that list the name of Josiah Marshall Heath. A more amiable, a more indefatigable and modest man he had never met. It had been his good fortune during a long series of years to have met many friends in connection with the pursuit to which he had devoted a somewhat long life, but he must say that among all those none occupied in his mind a warmer place than Josiah Heath, nor had he ever met a man who behaved, under very adverse circumstances, with such fortitude and resignation as he had done.

The PRESIDENT said it only remained for them to give their warmest thanks to Mr. Bauerman for his most interesting communication.

The following paper was then read:—

TILTING OPEN-HEARTH FURNACES.

BY ARCHIBALD P. HEAD, LONDON.

So far as the author is aware, all the open-hearth steel-smelting furnaces in use in this country are of the fixed pattern, being some variety of the original Siemens or of the "Batho" type. The object of this brief paper is to bring to the notice of this Institute the tilting open-hearth furnace, which has been in use for ten years in the United States, and seems likely to increase in favour, on account of the advantages it offers. It may, indeed, be regarded as the missing link between the Bessemer converter and the open-hearth furnace, partaking in its construction of some of the characteristics of each. In it, sound mechanical principles are applied to furnace building, the result being the work of a mechanic rather than that of a bricklayer.

Campbell Revolving Furnace.—The first furnace of this type was erected at the Steelton Works of the Pennsylvania Steel Co. in 1889, by Mr. H. H. Campbell. There are now ten furnaces of this type in operation at these works, *i.e.*, six of 45 tons, two of 18, and two of $4\frac{1}{2}$ tons capacity, all being basic lined.

The furnace body, Figs. 1 and 2 (Plate VIII.), revolves round its own axis on four rings of live rollers running on circular paths, and is operated by a horizontal hydraulic cylinder. The fixed gas and air ports come opposite a single oval aperture in the furnace ends. When the furnace is revolved, the gas and air ports are only partially closed. To allow the furnace free motion, a gap of about half an inch is left between the fixed ports and the furnace end, through which a certain amount of leakage of cold air necessarily takes place. Both the ports and furnace ends are faced with water-cooled cast-iron plates.

By a modification introduced by Mr. C. E. Stafford, the brick-work forming the ports is enclosed in an iron cage, which can be removed for repairs when required. The furnace roof is

made of silica bricks, ganister bricks having proved unsatisfactory owing to shrinkage. The charge is usually 80 per cent. of pig iron charged molten from the blast-furnaces, and the balance scrap. To charge cold pig iron or scrap, the furnace is revolved to an angle of 30 degrees with the horizontal, and the materials shot through the doors by shoots. The hearth is made specially strong to stand the wear and tear of this method of charging. About 14 heats per furnace per week are produced.

Wellman Tilting Furnace.—This furnace is the invention of Mr. S. T. Wellman. Instead of revolving on its own axis like the Campbell furnace, it is rolled or tilted forward, the furnace body being provided on the underside with two circular steel castings, which roll on and are supported by strong steel standards with horizontal upper surfaces. The rolling surfaces are provided with rack-work, which keeps the furnace parallel without supporting any of its weight. The tilting is accomplished by two hydraulic cylinders, mounted on trunnions at their lower ends. The upper ends of the piston rods are attached direct to the body of the furnace on the back or spout side.

To tilt the furnace, water is admitted to the top end of the cylinder. In case of accidental failure of the hydraulic system, the furnace returns by its own weight to the normal or melting position. There are now six of these furnaces in operation at the South Chicago Works of the Illinois Steel Co., viz., four 45-ton, and two 27-ton capacity. There are also others at work, viz., two at Burnham, two at Johnstown, Pennsylvania, and one at Milwaukee, Wisconsin.

In the earlier type of furnaces erected at South Chicago, the joint between the furnace and the regenerative chambers consists of a water seal, the ports being in one with the furnace and projecting therefrom at each end backwards towards the charging platform, and downwards the lower surface is provided with lips to rest in the troughs of the water seal, and is so arranged that when the furnace commences to tilt, the seal is broken vertically. In the later furnaces, however, the Stafford ports are adopted. These are divided into two portions by a vertical point, that nearest the furnace being the most frequently removed for repairs.

Latest Design.—The most recent of tilting furnaces is that

designed by Mr. S. T. Wellman for the new Alabama Steel and Shipbuilding Company's works at Ensley, near Birmingham, Alabama. The model on the table is a reproduction of this furnace to a scale of $\frac{3}{4}$ inch to a foot. It is also illustrated in Figs. 3 to 9 (Plates IX.—XI.). The works in question, which are now under construction, are for the purpose of making blooms and rails from open-hearth basic steel, the pig iron used being the phosphoric variety made in large quantities in and near Birmingham, Alabama, from the cheap southern ores. Up to now it has been taken for granted that ingot iron can be made more cheaply by the Bessemer than by the open-hearth processes, and where the greater variability of the product of the former process is not of vital importance, as in the case of rails, the Bessemer process, acid or basic, has hitherto been used. Owing, however, to the improved appliances which have of recent years been introduced in connection with open-hearth practice, especially in America, the difference in cost between the two processes has been steadily diminishing, until now in the above-mentioned steel works the open-hearth process is about to invade the field hitherto considered to belong exclusively to the Bessemer process, viz., the manufacture of rails. Among the mechanical improvements and labour-saving devices which have rendered this possible, mechanical charging and the tilting furnace play an important part. The electric charging machine for open-hearth furnaces was fully dealt with by the late Mr. Jeremiah Head in a paper before this Institute in May 1897. A model of the charging machine is shown on the same scale as, and working in conjunction with, the model of the tilting furnace.

The latest form of tilting furnace, as about to be installed at Ensley, Alabama, embodies the result of all past experience. There will be ten such furnaces in a row, each of 50 tons capacity, basic lined. If working with acid linings these would be rated as 60-ton furnaces.

Ports.—The gas and air ports are of novel construction, designed to minimise the leakage of cold air inwards at the joint. The two passages leading from the regenerative chambers to the ports terminate in two water troughs, about on the level of the charging floor. As before, the brickwork of the ports

is enclosed in a metal cage. But instead of being fixed, it moves upon flanged wheels running upon rails, which enable it to be moved a few inches towards or from the furnace end. The water troughs are so designed as to allow this small motion without breaking the seal. When melting is in progress the ports are moved up to the furnace, so that the face plates are in contact. When pouring is about to commence they are moved away so as to allow the furnace to tilt freely. The ports can be removed bodily for repairs.

Ladle.—It is intended that each furnace shall be provided with a casting ladle of a special design, attached to the front of the tapping hole, and forming in fact part of the structure. The ladle is provided with two pouring holes and stoppers. When the furnace is tilted for pouring, the metal, with the layer of slag on the top, flows into the ladle, and stands at the same level as in the furnace. Trains of casting bogies, each carrying two ingot moulds, are, as is usual in America, brought under the pouring holes. As the distance apart of the latter is the same as that of the moulds, two moulds can be filled simultaneously. An alternative method of casting will be to pour the steel through the plain spout into an ordinary ladle, provided with pouring hole and stopper, and suspended from an overhead electric crane. When filled, the ladle will be raised sufficiently high to be poured either into the moulds standing on bogies, or into bottom-cast moulds, arranged elsewhere in the casting-house.

Regenerative Chambers.—The regenerative chambers are arranged side by side in two pairs, one pair being at each end of the furnace, and extending under the charging platform. The portion of the charging platform in front of the furnace is upon solid ground, the valves standing above the level thereof, and being well out of the way at the back.

Body of Furnace.—In previous designs the body of the furnace has been round or oval in section, and enclosed in steel plates, somewhat after the manner of a boiler. It has been found, however, that this method of construction leaves something to be desired in point of strength. In the present case the furnace body is roughly rectangular in section. The whole furnace is enclosed in a strong cage, constructed of plates, channel bars and

angle bars, while stout tie rods bind the two ends together. There are also diagonal tie rods across the top, binding together the front and back, in such a manner as to prevent distortion and curvature. Indeed the same mechanical principles that regulate the design of bridges and other structures are observed here. The stress on each member is carefully calculated and allowed for.

Lining.—The furnace top, sides, and the outer layer of the bottom, are lined with silica bricks. The inside or basic portion of the bottom is made with magnesite, which is burnt on in thin layers about 1 inch thick at steel-melting heat. It is laid on with a large spoon and smoothed down, and when heated to the furnace temperature adheres to the next layer. Subsequent repairs are made with dolomite.

Valves.—The air-reversing valves are of the usual butterfly pattern, which being always comparatively cool, do not give trouble by warping and consequent leakage. The gas-reversing valves consist of two mushroom valves machined on their bevelled edges, and resting on circular seats with sharp edges. Both valves and seats are internally water-cooled. The water enters the valve by a tube inside the hollow stalk by which it is raised and lowered, and leaves by the annular space. Such valves are free from leakage, and are found to work satisfactorily. There is a chimney stack to each furnace.

Furnace Doors.—The furnace charging-doors are three in number, and are operated by pneumatic cylinders through wire ropes, the leads being arranged in such a way that the doors remain closed while the furnace is tilted. The doors are all 3 feet 6 inches broad by 3 feet high, which allows ample room for the insertion of the boxes of the charging machine. There are also small doors 18 inches by 2 feet at each end.

Angle of Tilt.—The angle of tilt, which for pouring is 25° with the horizontal, is regulated by stops which come in contact with the upper covers of the hydraulic cylinders when the extreme angle has been reached. By a simple mechanism these stops can be thrown out of gear, and a further tilt permitted when it is desired to drain off the slag.

Advantage of the Tilting Furnace.—The advantage of the tilting over the fixed furnace may be summarised as follows:—

- (1.) The slag, which, especially in the basic process, is

somewhat abundant and troublesome, can be poured off at intervals during the melting process. If allowed to remain, it forms a more or less non-conducting covering to the bath, preventing the access of heat.

(2.) As the pouring hole of the furnace is above the level of the bath in the normal position, it is never closed up, but only loosely covered to exclude the air. Consequently the time taken to open the hole before pouring, and to repair and close it after pouring, which sometimes amounts to one hour in an ordinary fixed furnace, is saved, as well as the labour connected therewith. The moment after the furnace is emptied the charging of materials can begin.

(3.) Since no injury is done to the pouring hole by opening and closing, the life of the furnace bottom is much prolonged. The occasional trimming required by the hole can be done at any convenient time.

(4.) The cold air which enters at the end ports when the furnace is tilted is an advantage, in that it chills the layer of slag on the surface of metal, which is as effectually prevented from boiling and spurting as if it were in a ladle.

(5.) In every fixed furnace small inequalities in the bed must exist in which pools of metal lodge, and can with difficulty be removed. This leads not only to a waste of metal but to a diminution of the capacity, and often to a distortion of the furnace bottom. In the tilting furnace every particle of metal and slag can be removed after each charge. A saving of metal of at least 2 per cent. has been effected by the tilting furnace as compared with the fixed furnace, which is ascribed to this cause.

(6.) The tapping of the charge can take place at the exact moment when the metal is of the desired composition. As no opening of the tapping hole is required, no time need be lost in that operation. The advantage of this is specially felt when steel of exact composition is required for special purposes.

(7.) In case of any hitch or accident during pouring, the furnace can be instantly tilted back, and pouring cease.

(8.) The tilting furnace lends itself readily to the transfer of metal from an acid to a basic furnace, or *vice versa*, as is practised at the Pennsylvania Steel Works.

(9.) The whole body of the furnace is easy of access for repairs or examination. Should a breakout occur, the regenerative chambers will not suffer, not being underneath the body, as is the case in the older form of Siemens furnace.

(10.) The furnace bodies do not become deformed, as in the case of fixed furnaces, since as structures they are much stronger.

The objections to the tilting furnace are as follows:—

(1.) It is somewhat more expensive than the fixed furnace.

(2.) The inlet of cold air during pouring in the case of the Wellman furnace tends to oxidise the manganese, which must be made up for by further additions in the moulds.

Conclusion.—The author ventures to hope that this short paper may convince the members that in the tilting furnace a substantial advance has been made in the metallurgy of steel, and one that is likely to have far-reaching effects in the future of the relative positions of the Bessemer and open-hearth processes.

He desires to acknowledge his indebtedness to Mr. S. T. Wellman of Cleveland, Ohio, and Mr. H. H. Campbell of Steelton, Pa., for much information, and for the drawings illustrating this paper.

DISCUSSION.

The PRESIDENT, in opening the discussion, said they had the good fortune to have Mr. Wellman with them, the inventor of the tilting open-hearth furnace described in the paper. Everything that tended to elucidate the use of the appliance was of such great importance that they were only too glad to hear any remarks that Mr. Wellman had to make.

Mr. S. T. WELLMAN said that he did not know that he had anything to add to what had just been said. The construction of the furnace was so simple and so well illustrated by the drawings, and the working parts and their movements by the model, that he did not see that there was anything left to be said by him, though he would be very happy to answer any questions that any of the members might wish to ask him.

Mr. GEORGE HATTON was sure that the inventive genius of our American cousins always received generous recognition by the Institute, and undoubtedly the credit of first making practical use of the tilting furnace was to be given to America. He did not know whether Mr. Head meant to lead them to infer from his paper that the furnace described in the diagrams was an invention of the Steelton Works, but he trusted that they would pardon him saying that in the year 1887—two years prior to the erection of that furnace—he had obtained British letters-patent for exactly that design of furnace. Unfortunately for him, perhaps, it was a little too previous—nobody seemed to want it at the time—and he allowed the patent to lapse. Perhaps they would allow him to say that much as a matter of historical interest. His patent was No. 13,248 of 1887. There were other things described in the specification than those Mr. Head had detailed and illustrated. With reference to the air-tight joints described by Mr. Head, he might say that he had been confronted with the difficulty of forming a sufficiently good joint between the ports of the furnace. He

thought the difficulty had been very much over-estimated. An absolutely air-tight joint was not necessary. There was always leakage through the doors of the furnace, and a small amount of air leading to the furnace from the port joints could not be very much objected to. He thought Mr. Wellman's attempt to get over that difficulty by means of movable blocks was rather unnecessarily complicated, and he thought that he could himself suggest a better way for dealing with the matter. Instead of mounting the furnace on rollers and rotating it on its own axis, or instead of rotating it on a rolling axis, if the furnace were to be mounted on a trunnion—and a hydraulic ram provided, it then could be lifted bodily, and the port joints would open freely from the commencement of the operation and the furnace could be turned over and placed in any position. The furnace would lift off those joints almost like the lid of a box, and be perfectly free from the joints, and it could also be closed down tight if it was thought desirable to add the water-cooled rings to the joint. No doubt that would be an improvement to the design of the furnace. He noticed that Mr. Head said that no repairs were needed to that furnace, but that they poured out the slag and put it back into position, so that no repairs were necessary. He thought that was contrary to experience. There was a great advantage in the use of tilting furnaces, inasmuch as one was able to free the furnace from all pools of metal, which otherwise were difficult to move from a furnace, and militated against making good substantial repairs. Mr. Head also had suggested that the usual practice was to pour out a portion of the slag during the process of conversion. He (the speaker) rather inclined to think that that would be a mistake. He thought that in the future these furnaces would be found more useful in dealing with hot metal from the blast-furnaces, because it might possibly be an advantage to retain some of the slag in the furnace and to add the hot metal to a portion of the slag from the previous charge. No doubt the furnace would be very useful where it was required to make small quantities of metal at a time and to facilitate taking it out.

Mr. R. M. DAELLEN said that his opinion was that the tilting furnace had many great advantages over the fixed furnace, but

he felt it would be rather difficult to introduce it generally, because it is a much more expensive installation than the ordinary furnace. He found, for instance, that in introducing what was called the Dick-Riley-Batho furnace in Germany, it had also very essential advantages over the original Siemens furnace; but people were always disposed to go back to the latter system because the other was more expensive in installation. The new furnace gave at first better results than the old type, but by altering it one obtained at last nearly the same success, and after the Batho patent expired it was a combined form which was now mostly adopted. Therefore his opinion was that Mr. Wellman should give more exact figures as to the economy and the capacity than were given with regard to the old system. He must say that by altering the old furnaces they were very satisfied in Germany with the results they had obtained, and there would be a great deal of difficulty in introducing the new system if there was not a real economy in the consumption of fuel, or in dealing with more charges in a day than one could at present, or in the duration of the furnace. These, he thought, were the three cardinal points.

Mr. DAVID COLVILLE said he would like to ask Mr. Wellman what the approximate cost of one of these large tilting furnaces would be, and also if, in Mr. Wellman's opinion, the one port of his furnace was as good as two ports where the furnace was so wide; and further, if he was not troubled with the roof of the furnace giving way, especially when the same was on tilt? He thought there would be difficulty. Then with regard to the shape of the ports on the drawing No. 6, he thought that the gas would destroy the roof, owing to its striking same, not being properly deflected, but perhaps experience would show that it would act differently. From the fact that Mr. Head described a removable port block in an iron casing, it would appear they had a good deal of difficulty with them when they made arrangements for so readily replacing them. He would like to know how long they would last.

Mr. SAMUEL T. WELLMAN said he thought it would be found that the furnace would adapt itself to many combinations of the

use of metal from blast-furnaces, and from one furnace to another, possibly in connection with some form of Bessemerising or desiliconising, but more likely he thought in combination with the use of two basic furnaces. A use of that kind would be found for the furnace, and it would be found very valuable, and that was what was contemplated at the works in Alabama, a combination of some processes of the kind indicated, as the blast-furnaces were located close to the steelworks. In regard to the question of the cost of these furnaces, their experience showed that they cost 25 to 50 per cent. more than a stationary furnace. It depended upon how well the stationary furnaces were built and how much iron was put in the binding of them, and so forth. The particular form of movable port shown in the furnace had not yet been tried for basic work, but it was proposed to try that at Alabama in the furnaces which were now in course of construction. Of course he could not answer yet the question as to the life of this particular furnace. There was no liability to any part falling out, as they could see—the binding over the roof came close to it. They did not find at the furnaces in Chicago any more trouble with the ports falling or melting out than was the case with the ordinary furnace. At Chicago they used ports seven feet wide with good results.

The PRESIDENT said Mr. Head deserved a cordial vote of thanks for his admirable communication, which had led to such an interesting discussion.

Professor HENRY LOUIS then read the following paper:—

NOTE ON AN IMPROVED DIPPING-NEEDLE.

BY HENRY LOUIS, M.A., Assoc.R.S.M., F.G.S.,

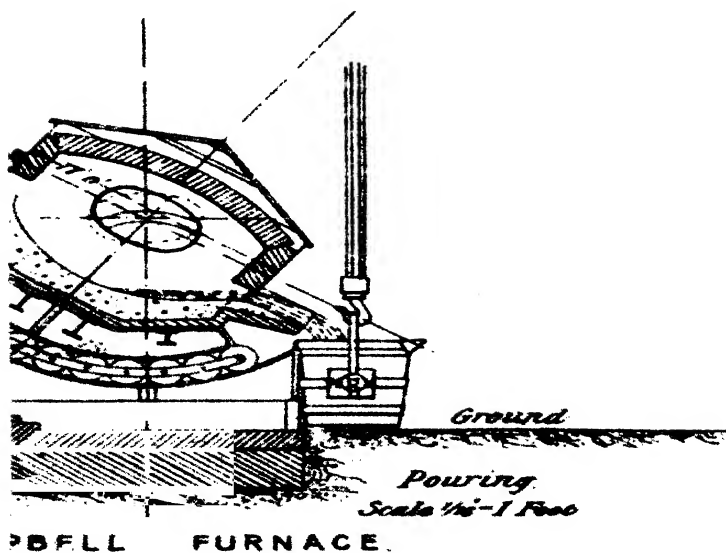
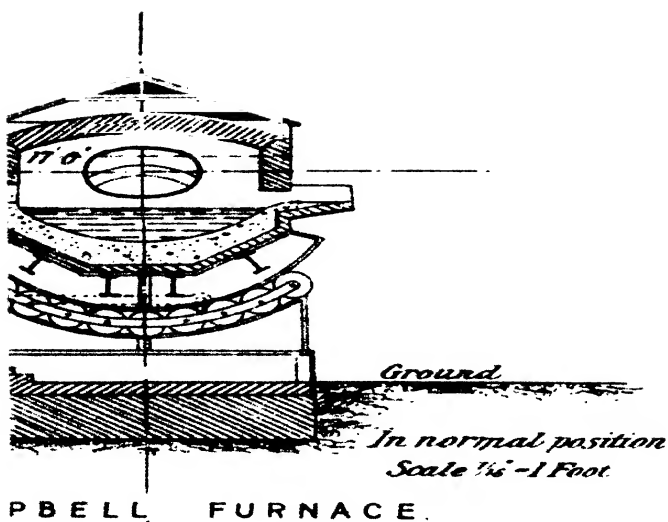
PROFESSOR OF MINING, DURHAM COLLEGE OF SCIENCE, NEWCASTLE-ON-TYNE.

IN the excellent paper read last year by Professor Nordenström,* and in that read in 1887 by Mr. B. H. Brough,† the Swedish methods of making magnetic surveys are very fully described. Practically two different types of instrument are used—one for preliminary prospecting, the other for detailed surveys. The former is, as stated in the papers referred to, a very crude appliance indeed. It has no graduation whatever, whilst the vertical angle has moreover to be estimated by looking down on the needle from above; in addition to which the mode of suspension of the needle, from a long tapered “cap” made of glass tube, leaves much to be desired. I have repeatedly seen two such compasses placed successively on the same spot of ground give very widely different indications. Its successful use depends therefore largely upon whether the particular instrument happens to be in good order at the time, and even more upon the personal equation of the user. Probably a man who has worked for many years with these instruments can learn to depend fairly well upon their indications; but these are hardly the qualities that are demanded of a scientific instrument.

The Thalen-Tiberg magnetometer, on the other hand, is an accurate piece of apparatus, and is relied upon in Sweden for giving exact information as to the magnitude and position of deposits of magnetic mineral. Good results appear to have been obtained by these methods in some cases, but my own experience of its application has been far from satisfactory. Of course I refer to instances in which the magnetometric maps had been constructed by experienced Swedish mining engineers, duly trained in the use of these instruments. Thus I have seen such maps in which the neutral line, instead of being, as theory

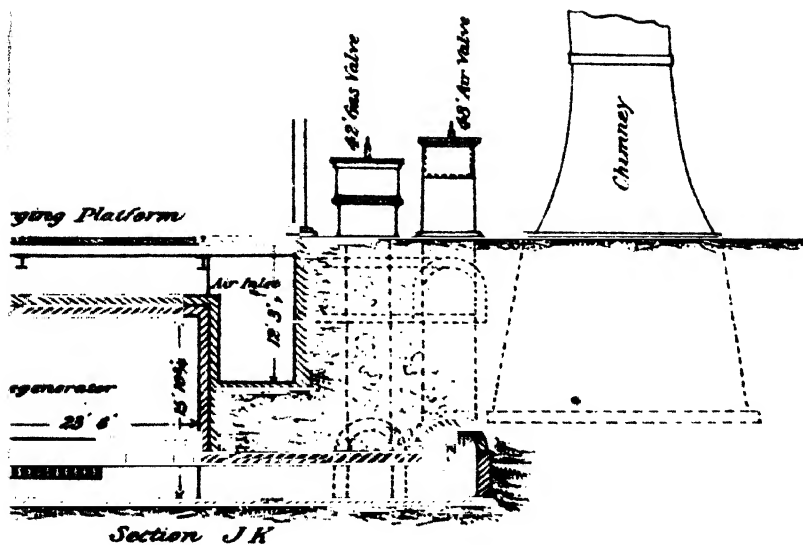
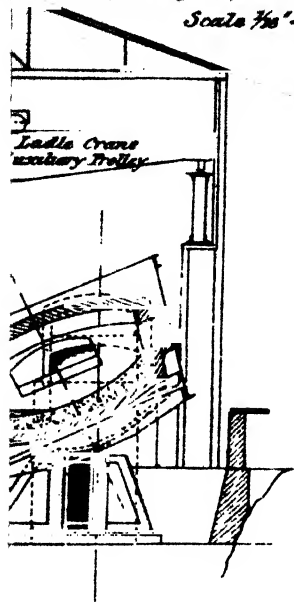
* *Journal of the Iron and Steel Institute*, 1898, No. II. p. 35.† *Ibid.*, 1887, No. I. p. 289.

PLATE VIII.



WELLMAN FURNACE

Pouring through Spout into Ordinary Ladle
Scale $\frac{1}{16}$ " = 1 Foot



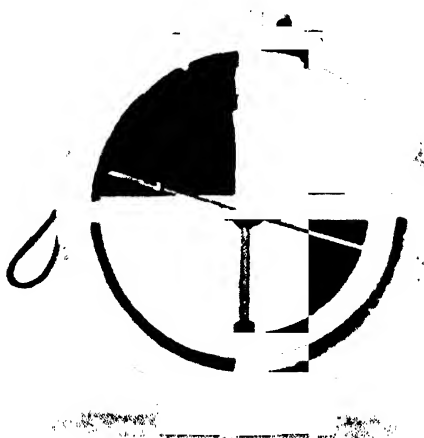
FURNACE
rough Special Ladle attached to Tapping Hole
Scale $\frac{1}{16}$ " = 1 Foot.

indicates, an open line, formed a closed curve; and again I have had occasion to examine a mine in which the presence of large quantities of magnetite appeared to be indicated by the magnetometric surveys, whereas mining operations revealed the presence only of small scattered pockets of rich ore. Seeing that magnetite deposits have not very often well-marked walls, and that the ore frequently shades off by almost imperceptible gradations into the surrounding country rock, it is difficult to see how in such a case magnetometric observations can indicate the limits of the ore deposit—*i.e.* from the miner's point of view, the quantity of ore that it will pay to extract. Again, it would seem that a mass, say of gneiss containing disseminated magnetite, or a basaltic dyke rich in ferrous oxide, gives indications not to be distinguished from those afforded by a mass of workable magnetite. Moreover, in very broken country, the fact that observations are made at different elevations complicates the problem very seriously. These various considerations have led me, rightly or wrongly, to look upon the magnetometer with a good deal of distrust. Magnetometric surveys are slow, laborious, and costly; none of these would be valid objections to their use if the results obtained were thoroughly reliable; but as it is, I hold that it is loss of time and money to employ careful quantitative methods, and only to get qualitative results.

On the other hand, however, I have thoroughly convinced myself of the value of the magnetic needle as an instrument for qualitative purposes—that is to say, for preliminary prospecting—and have hence for some time past endeavoured to devise a form of dipping-needle more sensitive and reliable than the Swedish prospector's compass, whilst at the same time less cumbersome than the magnetometer. For this purpose I have combined what I considered the best points of the Swedish and American dip-compasses, and have, at the same time, introduced a few modifications of my own.

The instrument shown in Fig. 1 consists of a circular brass box, 3 inches in diameter and $1\frac{1}{2}$ inch deep, the two flat sides of which consist of plates of glass. A flat-bottomed brass block screwed to the base of the box enables it to stand firmly on a level, or tolerably level, surface. The needle, $2\frac{1}{2}$ inches long, is suspended, as in the Swedish prospecting compass, from a little

stirrup; the latter is made of aluminium, and hung from an ordinary agate cap. The needle proper balances horizontally on delicate steel pivots, supported in the limbs of the stirrup by means of two watchmaker's jewels, so as to reduce friction to a minimum. Behind the needle is hung a graduated semicircular arc; this is not fixed, but is pivoted on a horizontal pin passing through its centre, so that in whatever position the brass box is placed the arc always hangs with its diameter horizontal. This diameter forms the zero-point of the graduation,* the pivots of the needle being exactly opposite the point of suspension of the



semicircular arc. The needle is fitted with a brass slider, so that it can always be adjusted in a horizontal position; the front glass plate is held in a pull-off cap, so as to enable this adjustment to be readily made. Above the needle is a long brass screw, which can be brought down on to the cap of the stirrup so as to hold it safely whilst the instrument is being carried. In the field the stirrup is released, and the instrument can be carried slung from a short piece of silk cord. As the graduated arc is suspended, and therefore self-adjusting, the amount of dip of the

* In the instrument shown the zero is wrongly placed, being vertically below the point of suspension of the arc. It is best to mark this point 0°', the running downwards from both right and left.

needle can be at once read off from it. In practice I find it convenient to carry the instrument in one hand and a light tripod (a hand-camera tripod answers admirably) in the other. To read the instrument, I simply set it on the tripod, no levelling being needed, and have thus both hands free for booking the declination. By walking in this way over the ground to be examined, the distances traversed being roughly estimated by pacing, the areas of maximum magnetic intensity can be determined with quite sufficient accuracy, and the data thus obtained, when compared with the horizontal deviations of the magnetic needle as read in the usual way on a small pocket dial, form a valuable supplement to those deduced from the usual methods of geological observation, &c., and deserve to be considered along with the latter in drawing conclusions as to the presence of magnetic minerals, or in deciding upon the disposition of prospecting operations.

I should add that in working out the practical details of this little instrument I have been greatly assisted by the maker, Mr. F. Robson of Newcastle-on-Tyne.

DISCUSSION.

The PRESIDENT said it seemed to him that the instrument was a most admirable one. Mr. Louis, occupying as he did an important professorial chair, was naturally an excellent judge of such appliances.

Mr. H. BAUERMAN thought that there might be some difficulty in ensuring coincidence between the centres of suspension of the needle and the divided arc; and the latter from its weight might be expected to wear oval in use, and so increase the eccentricity. Speaking from recollection of the tedious observations required in taking terrestrial magnetic dips in order to eliminate error of eccentricity, he thought that the method of observing one end of the needle only was open to question. However, within the limits proposed by Professor Louis, namely, that of giving indications of a somewhat more exact character than the ordinary Swedish hanging compass, the instrument would probably be found to be useful.

Professor H. LOUIS in reply said he could only say that the point that Mr. Bauerman had raised had not escaped him. The difficulty of suspension was got over first of all by carefully suspending the needle in the best way in jewelled bearings, so as to keep the point of suspension of the needle practically free from wear, by having the arc fairly light, and its suspension also of the best construction, and by having the vertical axis which carried the needle screwed into its socket, so that by turning it the point could be raised or lowered, so as to bring the point of suspension of the needle exactly opposite the axis of suspension of the arc. By this means the difficulty of false centering seemed to be fairly well got over.

A hearty vote of thanks was accorded to Professor Louis for his paper, and the proceedings were then adjourned till May 5, when the following paper was read:—

THE DIFFUSION OF ELEMENTS IN IRON.

BY JOHN OLIVER ARNOLD AND ANDREW M'WILLIAM, ASSOC.R.S.M.,

RESPECTIVELY PROFESSOR AND LECTURER IN METALLURGY
AT THE UNIVERSITY COLLEGE OF SHEFFIELD.

HISTORICAL.

MANY years ago it was shown by Sir Lowthian Bell and Sir Frederick Abel, that if steel and wrought iron were placed in close contact and heated, the iron gained and the steel lost carbon. In the *Journal of the Iron and Steel Institute*, 1897, I. p. 166 *et seq.*, Mr. G. P. Royston showed that the weight lost by hard steel was practically identical with the weight of carbon passing from such steel when heated *in vacuo* between wrought iron plates. Mr. Royston, supported by Mr. M'Millan, hence adopted Mr. Osmond's theory that the carbon in steel at a full red heat is in its elementary state in simple solution. It is difficult to understand why it should have been assumed that carbon must exist in an elementary state, and not as a carbide, before it is capable of diffusion through hot iron, or that the existence of the phenomenon of interpenetration should have been ignored. The gratuitous nature of the above assumption led Prof. Campbell of Michigan, U.S.A., to make a series of experiments on the diffusion of sulphur through hot iron, which were published in the *Journal of the Iron and Steel Institute*, 1897, II. p. 80 *et seq.* His results were not concordant, but some of his data, and the conclusion he deduced therefrom, were of such a startling and improbable nature that his work was hardly deemed worthy of serious discussion by theoretical metallurgists. Prof. Campbell stated that pure sulphide of iron would not diffuse through hot iron, but that oxysulphide of iron diffused through iron unchanged without contaminating the latter metal, and therefore pointed out that the fact of a triple compound thus rapidly diffusing deprived of all its cogency the claim that because carbon diffused it must necessarily do so in a state of elementary solution. Through the courtesy of Prof. Campbell,

per favour of Mr. R. A. Hadfield, the authors have received a complete series of samples admirably illustrating each stage of Prof. Campbell's work. To these the authors will refer in detail later, when it will be shown that although Prof. Campbell seems in error on one important point, namely, with reference to the alleged non-diffusive power of pure sulphide of iron, nevertheless the authors will have the utmost pleasure in directly confirming the accuracy of Prof. Campbell's general conclusion, and here congratulate him upon an important discovery in metallurgical physics, so remarkable and unexpected as to have been received with general incredulity. One of the most striking metallurgical announcements of recent years was made to the Royal Society by Sir William Roberts-Austen, when delivering the Bakerian Lecture on February 20, 1896. He showed that on fusing gold plates to the bases of bars of lead, that the gold-lead alloy interpenetrated the lead bars when the latter were merely maintained for some time at a temperature of 250° C., a point well below the melting-point of lead. He proved that at the end of a month molecules of the gold-lead alloy had actually travelled up to the top of the lead bars, a distance of no less than $2\frac{3}{4}$ inches. It has been shown by one of us and Mr. J. Jefferson, *Engineering*, 7th February 1896, that the gold-lead alloy in the cold metal appears to decompose during cooling into striae, probably consisting of alternating plates of lead and gold. Sir W. Roberts-Austen's results suggested to the authors the probability of similar molecular migrations taking place, with the compounds of the elements existing in that complex metal called steel. A full knowledge of the nature of such migrations is obviously of great practical importance in connection with the phenomena of segregation in steel ingots.

Experimental Methods Adopted.

The accurate quantitative chemical and micrographic measurements of molecular migrations taking place within a mass of steel is naturally a matter of some difficulty. It is obviously necessary to conduct experiments involving the maintenance of steel at a full red heat for many hours *in vacuo*, so as to avoid oxidation effects. It is also necessary to be able to accurately

measure and control the temperatures at which such experiments are carried out. Finally, the authors devised the following simple but efficient plan.

A cylinder of nearly pure iron, 3 inches long and 0.7 of an inch in diameter, was bored through dead true with a hole 0.35 of an inch in diameter. Bars of iron, containing usually about 1.5 per cent. of the elements, the diffusive power of which was about to be determined, were turned dead true to the exact diameter of the hole in the jacket. The latter was heated to about 150° C. to expand the hole a little, and the core was driven home, so that on cooling the bright surfaces of the jacket and core were in close contact. A chamber for the insertion of the thermocouple was made in the core, and the compound bar was introduced into a porcelain tube and heated *in vacuo* in the furnace figured by one of us in the *Proceedings of the Institution of Civil Engineers*, December 5, 1895. See also Fig. 1 of the present paper. After heating *in vacuo* for ten hours at a temperature ranging between 950° and 1050° C., the cold piece, which was always quite bright, was centred in the lathe, and the jacket turned down till a layer of only $\frac{1}{16}$ th of an inch remained on the core. This portion was then turned off and analysed to see if any of the element contained in the core had passed into the jacket. In some instances the two had welded, in which case the turning operation was stopped at a diameter $\frac{1}{16}$ th of an inch beyond the core to avoid any possibility of the latter being cut into by the turning tool. In many cases, however, it was possible to strip off the last few thousandths of an inch, leaving the core bright and smooth. The remarkable accuracy with which it has been possible to carry out these delicate mechanical operations reflects

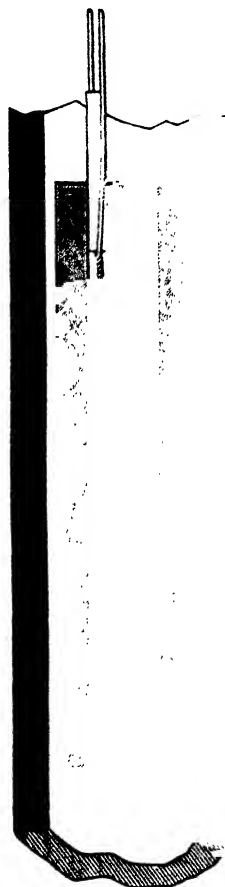


FIG. 1. (Full Size.)

great credit on the skill of Mr. Arthur Osborne, test-piece maker to the Metallurgical Department of the University College, Sheffield. The general analytical results obtained on testing the diffusive power of eleven of the elements of steel by this method are shown in Table I., which at 1000° C. divides the elements into two groups: (1) Migratory elements; (2) Fixed elements.

TABLE I.—*General Table of Diffusion Results.*

Test-pieces maintained at 1000° C. (± 50) *in vacuo* for ten hours. Jackets all 99.88 per cent. Fe. Cores nearly pure iron + tabulated percentages of the diffusing elements.*

| Elements. | | Original Percentage in Jacket. | Original Percentage in Core. | Percentage in the 1/8th of an Inch of Jacket adjacent to the Core after Experiment. | Percentage Diffused in 10 Hours. |
|------------|------------|--------------------------------------|------------------------------------|---|--|
| Migratory. | Carbon | 0.05 | 1.78 | 0.55 | 0.50 |
| | Sulphur | 0.02 | 0.97 | 0.12 | 0.10 |
| | Phosphorus | 0.015 | 1.36 | 0.11 | 0.005 |
| | Nickel | 0.00 | 1.51 | 0.11 | 0.11 |
| | Manganese | 0.05 | 1.29 | 0.04 | none |
| Fixed. | Silicon | 0.027 | 1.94 | 0.028 | .. |
| | Chromium | 0.00 | 1.10 | 0.00 | .. |
| | Aluminium | 0.02 | 1.85 | 0.02 | .. |
| | Tungsten | 0.00 | 1.41 | 0.00 | .. |
| | Arsenic | 0.02 | 1.57 | 0.012 | .. |
| | Copper | trace | 1.81 | trace | .. |

Microsections cut right through the compound bars were also polished, etched, and examined. The results, which are detailed below, practically confirm the chemical data.

*Results of Micrographic Analysis of Diffusion Bars in
General Table.*

Carbon.—The centre of the core consists of pearlite with large cementite meshes, dying away on the edge of the core to very slightly supersaturated steel. The inside of the jacket is about half saturated, the proportion of pearlite gradually diminishing towards the outside, until at the extreme edge it is almost the same as in the original iron.

* The complete analyses of these bars were published in the *Journal of the Iron and Steel Institute*, 1894, No. I. p. 115.

Sulphur.—The comparatively broad meshes of sulphide of iron in the core cross the junction, and in the iron appear as very fine veins, which become finer and finer until they die away.

Phosphorus.—Etching with dilute nitric acid shows clearly the coarse crystallisation of the core, and the surface has a distinct yellow colour which can be followed for about $\frac{1}{100}$ th of an inch beyond the junction, where it stops abruptly, being replaced from there to the outer edge of the jacket by the characteristic appearances of the pure iron. (See Section 1.)

Nickel.—In this section are seen two bands, one on each side of the junction, each about $\frac{3}{1000}$ ths of an inch broad, and differing in colour from both the core and the jacket.

Manganese.—Two rings about $\frac{2}{1000}$ ths broad, one on each side of the junction line, appear on etching.

Silicon.—The etching in this case does not bring out distinctly the whole of the border line, and although a ring of about $\frac{2}{1000}$ ths of an inch thick is developed beyond the edge, it seems more of the nature of a weld than an indication of any true diffusion.

Chromium.—The junction shows very clearly after etching, and there is no sign of diffusion. The carbide present in the core seems, however, to have retreated from the border, making a fairly regular circular outline about $\frac{1}{1000}$ ths of an inch from the junction line.

Aluminium.—No sign of movement shown on etching, the junction line sharply separating the appearances of the two surfaces. Very slight and short veins appeared in places round the outside of the core, but they would certainly be beyond the reach of analysis.

Tungsten.—No sign of any movement can be seen in this section, the junction line being the dividing line between the different appearances of the two etched surfaces, with only a slight iridescence in its immediate neighbourhood.

Arsenic.—On etching with dilute nitric acid, a slight iridescence similar to the strong iridescence produced all over the core extends over the border-line for a distance averaging only $\frac{1}{1000}$ th of an inch in width.

Copper.—The distinctive appearance of the etched copper steel core stops abruptly at the junction line.

In view of the facts that the diffusion of nickel was a result hardly to be expected, and that the diffusion of phosphorus was, as will presently be shown, of great theoretical importance, the authors thought it necessary to make further experiments with these elements. A second phosphorus test-piece was therefore built up and heated *in vacuo* at 1000°C . It was found that 0.065 per cent. of phosphorus had diffused in six hours as compared with 0.095 per cent. in ten hours. The first test was thus confirmed, and it will be noted that the above results show within 0.008 per cent. that the diffusions were directly proportional to the times for which the pieces were maintained at 1000°C .

With reference to the nickel, another test-piece was built up from a core of melted cube-nickel and the usual iron jacket. After ten hours *in vacuo* at about 1150°C ., the microsection showed no indications of diffusion or interpenetration. In this test no chemical data could be obtained, as it was found that the nickel core had bulged in driving into the cylinder, and had here and there assumed an elliptical shape, hence reliable turnings near the core could not be taken. Another test-piece was therefore prepared, using a core of nearly pure iron alloyed with 12.8 per cent. nickel. After ten hours at 1150°C . the piece was turned for analysis as usual. From this bar decisive evidence was obtained that the nickel really had diffused, as it was found possible to strip off a portion of the jacket, adjacent to the core, $\frac{1}{16}$ ths of an inch thick, leaving the nickel alloy bright and smooth. This strip of jacket was found to contain no less than 0.46 per cent. of nickel.

Section 2 shows the junction of the 12.8 per cent. nickel core with the iron jacket. The former shows a well-marked narrow altered band, and a broader but less marked zone is visible round the inside of the jacket. Owing to certain segregation appearances, the authors, under reserve, incline to the opinion that the nickel has diffused not in the elementary state, but as sulphide; a view strengthened by the fact that the nickel alloy was subsequently and unexpectedly found to contain a rather unusually high percentage of sulphur.

The data just detailed enable the authors to decisively answer the question—

Can an Element Diffuse through a Hot Iron Matrix in the Form of a Definite Iron Compound?

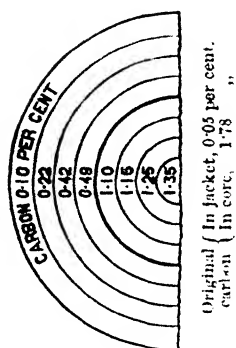
An accurate answer to the above question is of great importance in connection with the fundamental physics of steel. The authors have shown that four elements are capable of diffusing through solid hot iron. The manner in which nickel diffuses is doubtful, and this element may therefore for the present be dismissed from the discussion. There remain carbon, sulphur, and phosphorus. Carbon steels on heating present at about 700°C . a decisive absorption of heat, which Osmond holds to be a dissociation of normal carbide of iron (Fe_3C) into free iron and free carbon, and that the latter then becomes capable of diffusing in simple solution through the iron. Iron containing about 1 per cent. of sulphur presents on heating a decisive absorption of heat at 950°C . (see No. I. Plate XII.). This point may with some show of reason be claimed by those holding the theory of simple elementary solution to be a dissociation of FeS into iron and free sulphur, the latter then diffusing as such; hence there remains only the phosphorus diffusion, and here is reached solid ground. It is well known that the phosphorus in pure cold iron exists as a definite phosphide. On heating such material up to 1050°C ., only one critical thermal point is observed, namely, Ar_2 at about 725°C . (see Plate XII.); therefore, the phosphorus must exist in the iron as phosphide, not only in the cold, but also at a full red heat. But phosphorus has been experimentally proved beyond all doubt to be capable of diffusing, therefore it must diffuse as phosphide; therefore a definite compound can diffuse. But although phosphorus diffuses as a phosphide, it does not necessarily follow that carbon diffuses as a carbide, and it is therefore incumbent on the authors to answer, if possible, the vital question—

Carbon Diffuse in the Free State or as a Carbide?

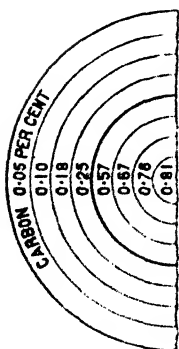
The above problem cannot be solved by multitudinous mathematical formulae based on deductions of dubious accuracy, but only by the results of numerous and direct experiments, such as the authors now place before the Institute.

Details of Experiments on the Diffusion of Carbon.

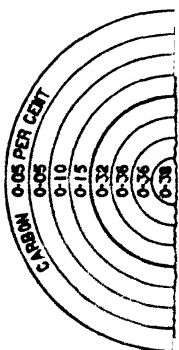
In order to comprehend the significance of the following data,



Original (In jacket, 0.05 per cent.
carbon) (In core, 1.78 " "



Original (In jacket, 0.05 per cent.
carbon) (In core, 0.89 " "



Original (In jacket, 0.05 per cent.
carbon) (In core, 0.38 " "

FIG. 2.

it is necessary first of all to study the chronographic heating curves of the various cores and jackets employed. These are plotted on Plate I. For preliminary trials three test-pieces were built up, all with nearly pure iron jackets, but (1) with an unsaturated core C 0.38 per cent.; (2) with a saturated core C 0.89 per cent.; (3) with a super-saturated core C 1.78 per cent. After exposure to a temperature of about 1000° C. *in vacuo* for ten hours, the three compound test-bars were sampled by turnings from eight concentric rings, four in the jacket and four in the core. The results are shown in Fig. 2, and are graphically plotted in Fig. 2A. The micrographic analyses of the compound sections gave the following results:—

1.78 per cent. carbon steel in pure iron.

—The centre of the core consists of pearlite with large cementite meshes, dying away on the edge of the core to very slightly super-saturated steel. The inside of the jacket is a little more than half saturated, dying away gradually till at the outer edge it shows almost the same pattern as the original iron.

0.89 per cent. carbon steel in pure iron.

—The centre of the core contains pearlite with ferrite meshes, evenly graded to the outside of the core, which consists of pearlite with a much greater proportion of ferrite. The inside of the jacket appears rather less than one-third saturated,

dying away gradually towards the outside edge of the jacket to normal iron.

0·38 per cent. carbon steel in pure iron.—The centre of the core is about half saturated, the edge of the core about one-third. The inner circumference of the jacket appears about one-fifth saturated, dying away on the outer circumference to normal iron.

The only conclusion definitely warranted by the foregoing data is that the higher the carbon in the core the more rapid the diffusion into the jacket, but the rate of diffusion seems to have no simple mathematical relation to the carbon percentage. The losses in the cores and gains in the jackets in the two high carbon tests balance fairly well, but the flow from the mild core seems less than the gain of the jacket, a fact doubtless due to small errors of analysis, and to the sampling being insufficiently delicate to give the true mean carbon in the concentric rings analysed. The foregoing preliminary experiments with a constant temperature and varying carbons thus elicited little of importance with reference to the specific point at issue. It was therefore decided to make a series of experiments in which jackets and temperatures should vary. The results obtained are very striking, and seem to negative the accuracy of the simple solution theory, and also to prove that at any rate normal carbide Fe_3C is capable of diffusing as an unaltered compound. The data obtained are set forth in Table II. :—

TABLE II.—*Table of Carbon Diffusion Results.*

| Carbon in Jacket per Cent. | Carbon in Core per Cent. | Hours Heated in Vacuo. | Temperature Maintained within a Few Degrees of | Carbon per Cent. in the $\frac{1}{16}$ th of an Inch of Jacket adjacent to the Core after Experiment. | Percentage of Carbon Diffused in 6 Hours. |
|----------------------------|--------------------------|------------------------|--|---|---|
| 0·05 | 1·78 | 6 | 636° C. | 0·05 | none |
| 0·05 | 1·78 | 6 | 739° C. | 0·05 | |
| 0·05 | 1·78 | 6 | 785° C. | 0·16 | 0·11 |
| 0·06 | 1·78 | 6 | 855° C. | 0·45 | 0·40 |
| 0·50 | 1·78 | 6 | 750° C. | 0·76 | 0·17 |
| 0·50 | 1·78 | 6 | 850° C. | 0·87 | 0·28 |
| 0·89 | 1·78 | 6 | 740° C. | 0·87 | none |
| 0·89 | 1·78 | 6 | 850° C. | 0·87 | |
| 0·89 | 1·78 | 6 | 900° C. | 1·20 | 0·31 |

It will be noted, on reference to the curves on Plate I., that all thermal changes in the 1.78 per cent. carbon cores used throughout are complete at 700°C ., therefore all variations in diffusion are dependent on thermal influences affecting the molecules of the nearly pure iron jacket. The table clearly shows that the free path necessary for the diffusion or interpenetration of foreign molecules is opened among the molecules of the iron immediately after the Ar_2 change-point, a point coincident with the evolution of gas from the metal *in vacuo*. The identity of Ar_2 with the diffusion of carbon into structurally free iron is further demonstrated by the test in which a jacket of steel, C 0.59 per cent., or two-thirds saturated was employed. Here it will be seen that considerable diffusion has taken place at 750°C ., because (see Plate XII.) the Ar_2 change in this jacket was complete at 720°C .

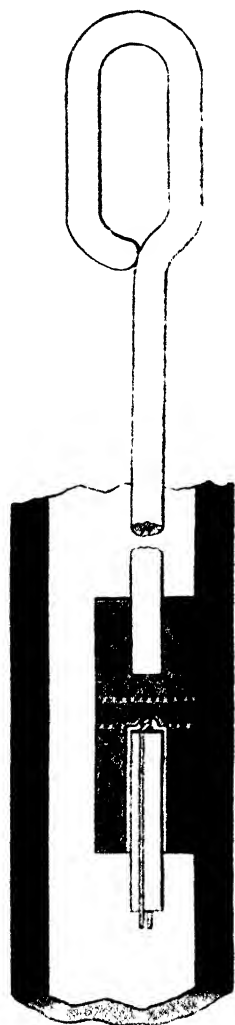


FIG. 3. (Full Size.)

The results registered on employing a saturated jacket C 0.89 per cent. are most remarkable. The Fe_3C of the super-saturated core will not diffuse into the Fe_{24}C of the saturated jacket till a temperature of at least 900°C . has been reached. In other words, the opening of a molecular free path under the influence of temperature takes place in Fe_{24}C , 150°C . later than in pure iron. The diffusive power of carbon, assuming unlimited time and excess of carbide, is represented with substantial accuracy in Fig. 3. The gap of about 150°C . in the diffusion line is, so far as the authors' knowledge goes, absolutely incomparable with any known data of the physics of saline solutions, and seems rather to point distinctly to the diffusion of two definite carbides of iron. The photo-micrograph shown in section 3

proves that not only did the cementite in the 1.78 per cent. carbon core fail to diffuse into the Fe_3C jacket at 850°C ., but also that it seems to have segregated slightly towards the centre of the core, leaving a saturated band inside the junction identical with the structure of the jacket outside. (The section figured is unetched, and the dots and splashes in the saturated areas are due to spaces formerly occupied by minute globules of sulphide of iron or to scoring effects produced by the detachment of such globules during polishing.) The micrograph figured in section 4 shows the junction of the 1.78 per cent. core and the 0.89 per cent. jacket heated at 960°C . It will be seen that the junction line is largely outlined in cementite from the core, and that the pearlite of the jacket has also been invaded by a molecular army of Fe_3C , the scattered units of which have as usual segregated into meshes on cooling. The vastly different configuration of the cementite in steels respectively heated to 850°C . and 960°C . is demonstrated in these sections with great clearness. The detailed micrographic analyses of the series embodied in Table I. are as follows:—

1.78 per cent. carbon steel in pure iron at 636°C .—The core shows pearlite and granules of cementite; the jacket, crystals of iron, the junction line being very marked, with no alteration rings of any kind.

1.78 per cent. carbon steel in pure iron at 739°C .—Shows the same appearances as the above.

1.78 per cent. carbon steel in pure iron at 785°C .—In this section there is a ring of about $\frac{1}{1600}$ ths of an inch on the outside of the core of saturated steel without cementite; and the iron of the inner portion of the jacket occurs in smaller crystals for a few thousandths of an inch farther out, resuming its normal form, but the increased carbon, clearly proved by chemical analyses, was not satisfactorily identified micrographically.

1.78 per cent. carbon steel in pure iron at 855°C .—The centre of the core consists of pearlite with granules of cementite, but on the outside of the core is a ring about $\frac{1}{1800}$ ths of an inch in width of saturated to very slightly super-saturated steel. The inside of the jacket is about half saturated, the pearlite gradually diminishing towards the outside to almost the proportion seen in the original iron.

1.78 per cent. carbon steel in 0.59 per cent. carbon steel at 750° C.—The description of this could only be given from memory, as the microsection has been mislaid, but it confirmed the chemical analysis.

1.78 per cent. carbon steel in 0.59 per cent. carbon steel at 850° C.—The centre of the core presents the usual appearances, but on each side of the junction line is a band of saturated steel about $\frac{1.4}{1000}$ ths of an inch broad, tapering off in the jacket to almost the original appearance of the 0.59 per cent. carbon material.

1.78 per cent. carbon steel in saturated steel (0.89 per cent. C) at 740° C.—The distinctive characters of each of these steels ends abruptly at the junction line, showing no altered ring of any kind.

1.78 per cent. carbon steel in saturated steel at 850° C. (see section 3).—In this case a curious phenomenon is clearly seen either on the section as taken from the polishing block or after etching. The jacket shows over its entire surface the usual appearances characteristic of saturated steel, and the centre of the core pearlite with granules of cementite, but on the outside of the core appears a ring of saturated steel about $\frac{1.7}{1000}$ ths of an inch broad, showing that at this temperature none of the carbon had moved outwards into the jacket, but that the cementite had begun to segregate towards the centre of the core. It would thus seem that at this temperature the movement among the particles of cementite due to the high temperature had not yet overcome the attraction of the like molecules of cementite.

1.78 per cent. carbon steel in saturated steel at 960° C. (see section 3).—The core consists of pearlite with meshes and needles of cementite. The inner portion of the jacket is composed of pearlite, with finer meshes of cementite dying away outwards to ordinary saturated steel.

The Quenching and Hardening of Steel.

The data already given and discussed enable the authors to deal with some certainty with the rival theories put forward to account for the hardening of steel on quenching from a full red heat; but as this cannot be done without reference to micro-

graphic analysis, it is unfortunately necessary in the first instance to refer to that chaos miscalled micrographic nomenclature, which, to the authors' certain knowledge, is the despair of many an earnest student. All the generally recognised and important micro-constituents of pure iron and carbon steels were discovered and qualitatively described by Dr. Sorby. In the hope that it may help students, the authors have prepared the following key to synonyms:—

1. *Ferrite*.—The iron of Dr. Sorby, christened ferrite by Professor Howe. It usually occurs in allotrimorphic crystals resulting from the interference of cubic crystals.

2. *Pearlite*.—The pearly constituent described by Dr. Sorby as consisting of alternating plates of soft iron and an intensely hard substance rich in carbon. This was christened pearlite by Howe, and has been shown by one of us to consist of iron in which is suspended in laminae or granules, according to the rate of cooling, 13 per cent. of the normal carbide of iron, Fe_3C .*

3. *Cementite*.—The intensely hard constituent of Sorby, christened cementite by Howe, may occur massive, in sectional meshes, in streaks, or in granules. The surplus carbide of one of us.

4. *Graphite*.—Described by Sorby as occurring in pig iron in elongated plates, and by one of us in steel as rosettes, the last-named being the temper carbon of Professor Ledebur.

5. *Martensite*.—Described by Sorby as a structureless compound existing at high temperatures, which on cooling splits up into alternating plates of iron and an intensely hard substance rich in carbon. Christened hardenite by Howe; rechristened martensite by Osmond. This is the subcarbide of iron, Fe_{24}C , of one of us. The substance now generally called martensite is obtained by quenching out saturated steel from a full red heat. Sorby describes martensite as practically devoid of structure, a conclusion confirmed by one of us. Osmond states that martensite consists of a series of needles, interlacing at an angle of 60° . Mr. A. Sauveur verbally confirmed Osmond's description, but himself figures martensite as a dead black structure, a representation obviously diagrammatic. Osmond and Sauveur have both denied the accuracy of the structure of hardened steels

* The discovery of this compound by Sir F. Abel and Dr. Müller quite independently of each other is one of the most important landmarks in the history of steel.

figured in a paper on the "Influence of Carbon on Iron," read before the Institution of Civil Engineers, December 1895. They state that any steel containing from 0.10 to 1.00 per cent. carbon quenched out from a temperature of 1000° C. consists of martensite, and contains no structurally free iron. This statement is not only inaccurate, but, from a practical point of view, absurd. It is also, bearing in mind that the nomenclature of metallography is supposed to be in accordance with the precedents of mineralogy, insupportable from a theoretical standpoint. The facts of the case with reference to pure iron and carbon steels quenched out at a fair red heat, say 850° C., are as follows:—Saturated steel, carbon 0.9 per cent., consists entirely of martensite, which appears amorphous, and on etching with dilute nitric acid is covered with a velvety black deposit of liberated carbonaceous matter, readily removed by the finger. Unsaturated steel (say carbon, 0.3 per cent.) contains particles of structurally free ferrite mixed with dark particles consisting of a molecular mixture of martensite and ferrite. If, however, the above steel be slowly cooled down to just above the carbon change-point at 680° C., and be very suddenly quenched, the structure will contain two constituents, one ferrite (Fe) and the other martensite (Fe_2C), in the respective proportions of 2 to 1. On quenching a supersaturated steel containing, say, carbon 1.5 per cent., the matrix will consist of martensite, overlaid sometimes by a network of cementite, or sometimes the latter will be scattered over the matrix in the form of granules. The accuracy of the foregoing facts, so far as they deal with unsaturated steels, is demonstrated by the following special microthermal investigation on

The Influence of Quenching on Mild Steel.

The steel selected by the authors for these trials contained 0.21 per cent. carbon, 99.64 per cent. of iron, and 0.15 per cent. of total impurities. In round numbers, the microsection of the normal steel consists of 25 per cent. of pearlite and 75 per cent. of ferrite. It will be obvious that each granule of pearlite, with its surrounding matrix of ferrite, represents on a very minute scale a core of saturated (0.9 per cent. carbon) steel enclosed in a nearly pure iron jacket. The quenching test-pieces were

prepared as shown in Fig. 3, having a recess at one end for the insertion of the thermo-couple of the Le Chatelier pyrometer, and one at the other end for the rod used for instantaneously withdrawing and quenching the sample at the desired temperature. It will be noticed that the thermo-couple was in actual contact with the piece of metal subsequently machined out for microscopic examination from the position shown by the dotted lines in the figure. The experiments were carried out in the apparatus shown in Fig. 4. The gasholder contained nitrogen, which passed through the washing bulbs A and the drying tube B into the porcelain tube D, the ends of which were stoppered with asbestos. The furnace, C, was then heated till the pyrometer had

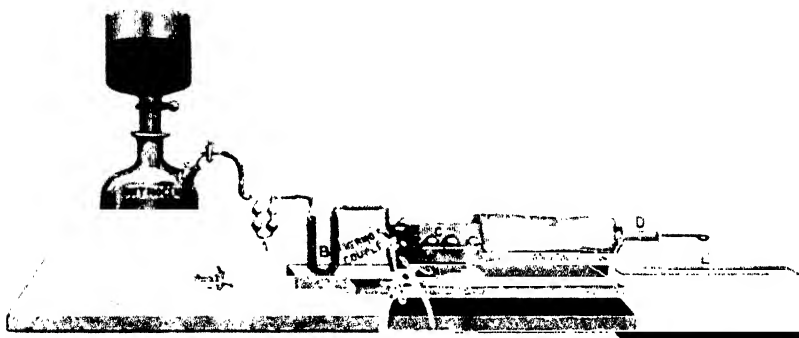


FIG. 4.

risen to a little over 1000° C., when the gas and air were turned off. A series of quenchings at different temperatures were made and microsections prepared. The results are shown in correlation in Plate XIII. It will be seen that the relations between the critical points and the quenching temperatures were in each piece checked by chronographic curves of recalescence. The quenchings made in the tank E, Fig. 4, which was filled with saturated brine at about 12° C., were practically instantaneous, and the position of the microsection such that its internal temperature on quenching would be identically that indicated by the pyrometer. Oxidation results were of course eliminated by conducting the heatings and coolings in an atmosphere of dry nitrogen. The microsections were polished and then etched for

10 seconds at the same time in one dish with nitric acid of sp. gr. 1.20. After washing, their surfaces were lightly rubbed with the finger under absolute alcohol, to remove loosely-adhering carbonaceous matter. They were then examined, repolished, re-etched, &c. The structures were found to be constant. They were then photographed, and their structures are figured together with their respective recalescence curves (actually observed lines in full) on Plate XIII.

The section quenched at 975° C. consists of a very intimate mixture of pale particles of structurally free ferrite, and of dark particles, evidently of iron contaminated with much unsegregated martensite.

The section quenched just above Ar3 shows a similar structure, but the pale and dark particles are slightly larger, and the pale areas relatively greater. In the section quenched below Ar3 the proportions of light and dark areas are about the same as in the last section, but the pattern is much larger and the junctions between the crystalline grains of ferrite are distinctly visible.

The section quenched in the middle of the Ar2 change scarcely differs from that last described.

The section quenched just above Ar1 shows much the same pattern as the last, but the ferrite areas are distinctly larger.

The section quenched below Ar1 shows a structure scarcely differing from that of the normal steel. By this method of quenching it is almost impossible to obtain reliable data as to the temperatures at which carbonised micro-constituents segregate in unsaturated steels, but the results prove that the structure of mild pure iron and carbon steel quenched at 1000° C. does not consist of interlacing needles of one constituent, neither when quenched at various temperatures below that heat does it exhibit, even when carefully examined at high powers, any signs of the "transition" constituents, sorbite and troostite, described by Osmond; in fact, under no circumstances can transition diffusion products, which necessarily must be indefinite mixtures, claim to rank as specific micro-constituents.

Consideration of the "Carbon Solution" and the "Carbide Diffusion" Theories.

The time now seems to have arrived when it is possible, in the light of new data, to dispassionately discuss the relative probabilities of these two theories. According to the solution theory, at 700° C. the carbon and iron of the normal carbide (Fe_3C) dissociate, and the carbon passes in a simple state of elementary solution into the surrounding iron. Then if the steel containing such dissolved carbon be cooled down to the critical point Ar1 at 680° C., the free iron and carbon again combine to form Fe_3C . Let this reasoning be applied to a steel containing 0.3 per cent. carbon. Heat the steel to 1000° , and maintain it for a little time at that temperature. It is generally admitted that the carbon, in whatever form it exists, will now be evenly diffused throughout the steel. Next, allow the steel to somewhat slowly cool down to the ordinary temperature, and it is again admitted on all hands that its microstructure will consist of two-thirds ferrite and one-third pearlite. It is also agreed that before the Ar1 change took place to form the pearlite, the areas occupied by the latter had segregated (forming martensite). Now if the solution theory be true, the following extraordinary phenomena must occur. At 1000° C. there is a solvent (iron) permeated with dissolved carbon atoms, but when the temperature is allowed to fall a little below 700° C. the dissolved free carbon abandons two-thirds of its solvent, and concentrates itself into the remaining one-third to form a saturated solution! The authors, in common with most metallurgists, reject the foregoing theory as unreasonable, because if only the phenomena of simple solution are involved, there seems no valid reason why, as the solvent iron cools, the dissolved carbon atoms should not remain *in situ*, and the distribution of Fe_3C in the cold metal be even throughout the mass.

On the other hand, now that it has been definitely proved that a compound can diffuse through red-hot iron, the last objection to the sub-carbide theory seems to have been removed. Applying this theory to the case of the 0.3 per cent. carbon steel at 700° C., the pearlite areas (21 Fe + Fe_3C or Fe 87 per cent., Fe_3C 13 per cent.) become sub-carbide of iron, Fe_{24}C . This

remains *in situ* till the temperature has risen to 750 C., and the iron surrounding it has passed through the Ar₂ change, then the iron and the sub-carbide molecules interpenetrate as the temperature rises until density equilibrium is established, say at 900° C. On cooling to, say, about 750° C., the hitherto mixed molecules begin to segregate to a series of centres each to its own kind; and given a sufficient time at many degrees before the recalescence point at Ar₁ is reached the ferrite and martensite are established in their separate areas. Then at Ar₁, or at about 680° C., the martensite or Fe₃C decomposes into pearlite, *i.e.* a definite mixture of iron and Fe₃C; then if the piece be maintained under the influence of slow cooling, the molecules of the iron and normal carbide undergo a distinct segregation very similar to that taking place just previously in the molecules of the iron and the sub-carbide.

Sir William Roberts-Austen in his fifth report to the Alloys Research Committee of the Institution of Mechanical Engineers proposed as an analogue for steel the phenomena observed in the freezing of brine solutions. The authors gladly welcome this analogue, inasmuch as it appears inapplicable to the carbon solution theory, but exactly falls into line with the sub-carbide diffusion theory. There exists in brine solutions a hydrate of sodium chloride of constant and definite composition. On freezing the solution, this hydrate and the water not in combination with the salt segregate, forming ice and a solid cryohydrate, which latter decomposes into a "eutectic," *i.e.* alternating particles of salt and ice. So in hot unsaturated steel there exists diffused amongst the iron a definite sub-carbide. On cooling the mass, the iron and sub-carbide segregate, and the "cryocarbide" finally decomposes into the "eutectic" pearlite, consisting of alternating particles of Fe and Fe₃C. The analogy seems perfect.

*The Diffusion of Sulphide and Oxysulphide of Iron through
Hot Metallic Iron.*

The authors have now to return to the most valuable research of Professor Campbell, and to remove any lingering doubt as to the reasonableness of the theory involving the permeation of hot

iron by the unchanged molecules of an iron compound. Fig. 5 shows three typical specimens used in Campbell's investigation. A is pure mild steel, bored with a hole subsequently charged with sulphide or oxysulphide of iron, and then plugged. B shows the section of an oxysulphide diffusion piece after being maintained at a red heat for some hours. The chamber is empty. The oxysulphide has permeated the steel in every direction, and has become involved in the scale covering the outside of the piece, which Professor Campbell found to be very rich in sulphur, although the metal itself had absorbed little or no sulphide from the diffusing compound. It is important to note in the photograph that the top of the piece, as well as

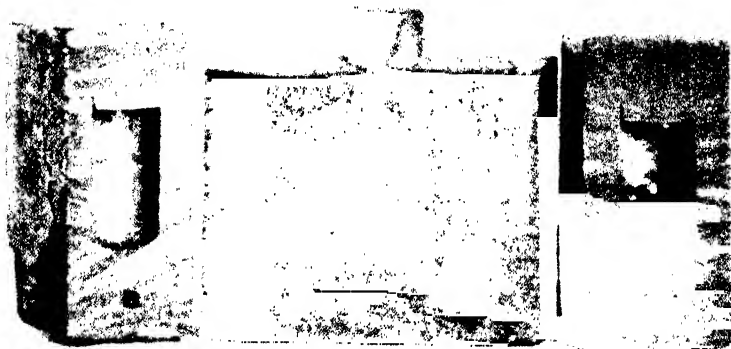


FIG. 5. —DIFFUSION PIECES USED IN CAMPBELL'S TEST.

the sides, is thickly covered with this scale. C shows a section of a pure sulphide of iron diffusion test in which the sulphide has merely melted and settled down in the chamber without diffusing. In order to confirm or confute the remarkable deductions of Professor Campbell, the authors made the following experiments:—

Holes 2 inches deep and $\frac{3}{4}$ inch diameter were drilled in two polished bars of nearly pure iron 3 inches long. Into these holes were pressed in fine powder about 7 grams each respectively of Campbell's oxysulphide of iron, and of some almost chemically pure FeS prepared by the authors. The tubes were then hermetically sealed by gas-tight screwed plugs $\frac{1}{2}$ inch long. The

test-pieces were heated *in vacuo* for about six hours at about 1150°C . On cooling, after the experiment, to about 500°C ., the vacuum suddenly dropped, and it was found that the porcelain tube had cracked. The test-pieces were immediately removed, and quenched out to stop scaling. No. III., Plate XVIII., shows a section of the FeS test before heating, and a photograph of the bar after the experiment. Both in the case of the sulphide and of the oxysulphide bar the chambers were practically

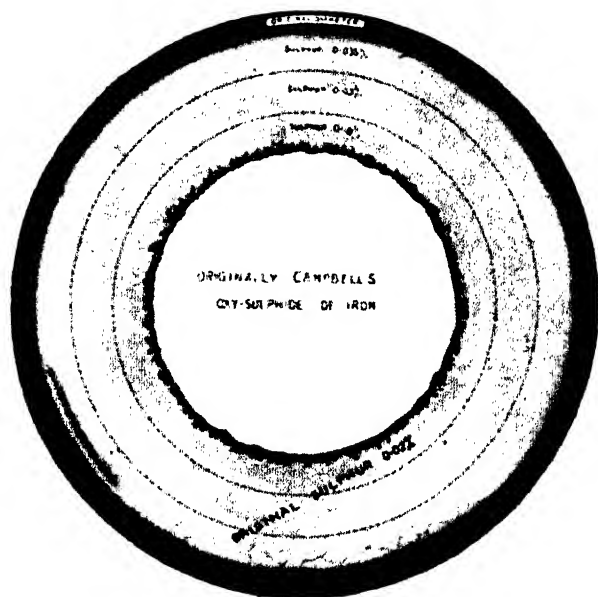


FIG. 6.

empty. The compound molecules had passed unchanged through the molecules of an air-tight wall of iron at least $\frac{3}{16}$ th of an inch thick, and had collected about the lower halves of the bars. Microsections, necessarily somewhat diagrammatic, taken through the centres of the test bars, are shown in Figs. 6 and 7. After clearing the outsides of the bars from adherent sulphide and oxysulphide, they were sampled for analysis in three concentric rings. The results are shown in the figures. Both inner rings showed little streams and pools of sulphide, left as it were at high-water

mark by the receding molecular tide. The central layers had taken up respectively only 0.01 and 0.02 per cent. of sulphur. The outer layers show a slightly greater increase, due to the fact that the lower halves of the bars immersed in the molten compounds at the bottom of the tube had absorbed a little sulphur, which appears under the microscope as a fine meshwork. The oxysulphide seems to have diffused more completely than the sulphide, as a small quantity of the latter was found adhering to

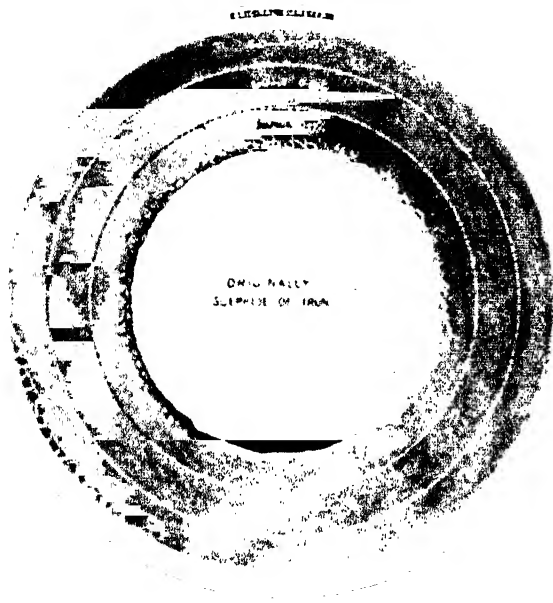


FIG. 7.

the sides of the chamber, as shown in Fig. 7. Such patches were of course avoided in sampling for analysis. The foregoing are the facts, there will be no lack of theories to account for them, but with such the authors will not meddle at present, further than to remark that it seems probable that internal gaseous pressure must have had some influence in bringing about the ignominious expulsion of the liquid sulphide through the narrow paths between the iron molecules from the inside to the outside of the tube.

The authors have to cordially acknowledge the great assistance they have received from Mr. Fred. Ibbotson, B.Sc., and Mr. J. Jefferson, Assoc.R.S.M., in preparing the diagrams and photomicrographs illustrating this paper.

They have finally, against his expressed wish, to tender their warm thanks to Mr. R. A. Hadfield for generous financial assistance, without which the publication of this research must have been indefinitely postponed.

DISCUSSION.

The PRESIDENT said that before he invited discussion on the paper, he would like to be allowed to mention that, owing to a typographical error in the Report of the Council read yesterday in reference to the death of the great French ironmaster, Henri Schneider, there was an omission of the fact that Mr. Schneider had received the Bessemer gold medal in the year 1889. As Mr. Schneider was the initiator of the great advances which had been made at Le Creusot, which had made that great works famous throughout the world, he was a member of whom the Institute was naturally very proud, and whose sad loss they deplored. He was very glad indeed to note that among the new members who were elected yesterday was Mr. Saladin of the Creusot Works, and he took the opportunity of offering that gentleman their very cordial welcome.

They all of them listened at that Institute with great interest to any observations that came from Professor Arnold, and from his (the President's) old student Mr. M'William, and, in fact, from any member of the great industrial centre, Sheffield, which was so worthily represented by Professor Arnold and Mr. Hadfield. He now invited discussion on this exceedingly interesting subject of diffusion in iron, and as the paper was one of very great difficulty, it would be, perhaps, well to point out that the main points, as he took it, for discussion were, "Can an element diffuse through a hot iron matrix in the form of a definite iron compound?" and "Do the results negative the accuracy of the simple solution theory, and also prove that at any rate normal carbide of iron, Fe_3C , is capable of diffusing as an unaltered compound?" It would perhaps save time to define the discussion as being on those main points.

Mr. J. E. STEAD, Member of Council, complimented the authors of this paper upon the very important facts that they had brought forward, for he considered that the facts were the things that they must look to before formulating any theory.

The question of diffusion, and as to the condition or way in which carbon passed through and moved about in steel and in iron, was a most important one. On the first page there was a reference to a certain experiment made by Mr. Royston. That was an experiment which rather tended to disprove, he thought, Professor Arnold's conclusion that the carbide of iron itself diffused in the mass. Mr. Royston placed a bar of steel containing carbon and a bar of pure iron together and heated them, the bars being carefully weighed before and after the experiment. After the experiment was over, the bars were cooled and again weighed and analysed. The iron bar had increased to a certain extent in carbon, and had increased in weight exactly to that extent, and no more. One would naturally assume that if Fe_{24}C or Fe_3C had diffused from one bar to the other, there would have been a loss corresponding to the carbide, and not to the carbon only; but, as a matter of fact, the result showed clearly enough that the increase was due to the carbon alone. That would rather strengthen the theory that the carbon in some form or other had passed from one bar to the other, and had not carried any iron with it, unless, of course, they accepted the hypothesis that a corresponding amount of iron had passed back again from the iron bar into the steel bar.

A large number of results showing diffusion were given by the authors. It would have been very interesting if they had weighed the rings before and after each experiment, and so ascertained whether the increase in weight corresponded to the carbon, sulphur, phosphorus, and nickel diffused, or of the elements plus something else. Perhaps they would continue their experiments in that direction.

Phosphorus and iron formed a liquid compound when heated, sulphur and iron also formed a liquid sulphide of iron. One could understand liquids diffusing into liquids and liquid sulphides or other liquids diffusing through porous solids, but it was more difficult to explain the diffusion of a solid definite chemical compound through a solid.

Referring to the absorption points shown by Professor Arnold at 950° for sulphur, he took it that that was the point at which the sulphide of iron actually became liquid in the heated bar.

That accounted fully for that absorption point. It was highly probable that the liquid might diffuse from that point, but because a liquid in a solid diffused through a solid, he did not think that they must necessarily conclude that a solid definite chemical compound, which was not a liquid, would pass through a solid as such, and did not.

The phosphide of iron was also a fusible compound, but he did not think that the curve shown indicated any melting-point of phosphide of iron. There was no arrest indicating a liquefying phosphide there, unless it was a gradual liquefaction—unless that gradual rise in the curve exhibited showed the phosphide gradually passing into solution, or absorbing the surrounding particles—it did not, however, seem probable.

In the paper reference was made to Mr. Jefferson's experiments upon gold and lead alloys. He (Mr. Stead) might correct that point. The stria which separated out in lead-gold alloys did not contain any free gold, at least in the case when the lead was in great excess; it was a definite compound of gold and lead as definite as Fe_3C . He happened to have thoroughly studied the gold-lead alloys.

Some time ago he made certain trials to ascertain whether or not oxy-sulphide of iron would diffuse through solid steel, but his experiments did not verify fully Professor Campbell's results. He only made one trial. Apparently the conditions for diffusion were so delicate that even Professor Campbell himself got varying results under varying conditions.

For instance, in his first paper he found after diffusion that there was no oxy-sulphide whatever left in the steel itself, but that it passed completely through the steel; then he tried another experiment, and found that he did get a little sulphide left. Then he stated that he could not get sulphide of iron to diffuse; it must be an oxy-sulphide. He also stated that one could not get an oxy-sulphide to diffuse unless the steel was heated in an oxydising atmosphere. Now the authors came forward and asserted that sulphide of iron *per se*, without any oxide whatever, would diffuse quite freely, that oxygen or oxide of iron on the envelope was not necessary, and that the diffusion took place *in vacuum*. They were most startling results, but, as he had said two or three years ago, he still thought the matter required much more investigation.

There was something underlying all this that they did not know about, and he thought it was a most important subject to study. They were simply in a fog at present, and could not explain the exact nature of the changes which took place when solids or liquids diffused into solids. Theory and discussion would probably direct their attention to certain grooves in which practical experiment should be made to enable them to explain it satisfactorily. They were not in a position as yet to dogmatise.

He should like to ask the authors a very practical question, which would appeal more to manufacturers than to anybody else. If sulphide of iron would filter to the outside of a piece of steel in his laboratory, why should not all the sulphides in our English steels diffuse through and drip out at the bottom on to the hearths of our furnaces? He had found that in most steels containing manganese the sulphur was combined with that element. Probably sulphide of manganese did not diffuse like sulphide of iron. Perhaps Professor Arnold would give his views upon that question.

Mr. R. A. HADFIELD, Member of Council, said he was very glad to have been an intermediary between the authors and Professor Campbell, as he thought the results given in the paper were most interesting. Professor Arnold was very thorough in his experiments, which had evidently been carried out with great care and accuracy. The matter was really a very important one, because it concerned very largely, directly or indirectly, an important branch of industry, namely, the manufacture of armour-plates. He believed the paper would be one furnishing a good deal of information to those interested in this special manufacture. He would like to call attention to the passage where Professor Arnold particularly pointed out that his samples were those of a very pure character, only containing 0.15 per cent. of total impurities besides the carbon. He thought investigators were often led astray by working on specimens to which sufficient attention had not been given regarding purity.

Quite recently a number of results had appeared abroad, and the samples were represented as being carbon steel, but they also contained other elements—manganese, for example, being

present to as much as 0·3, 0·4, and even 0·5 per cent. He thought that in consequence a number of incorrect conclusions had been drawn from these tests. He specially called the attention of the meeting to the fact that Professor Arnold had been experimenting with practically a pure carbide of iron, or rather with a very low mild steel. He asked Professor Arnold whether he understood correctly that, when talking of martensite, they really might conclude that its composition could be safely taken to be as represented by the analysis mentioned, namely, Fe_{24}C ?

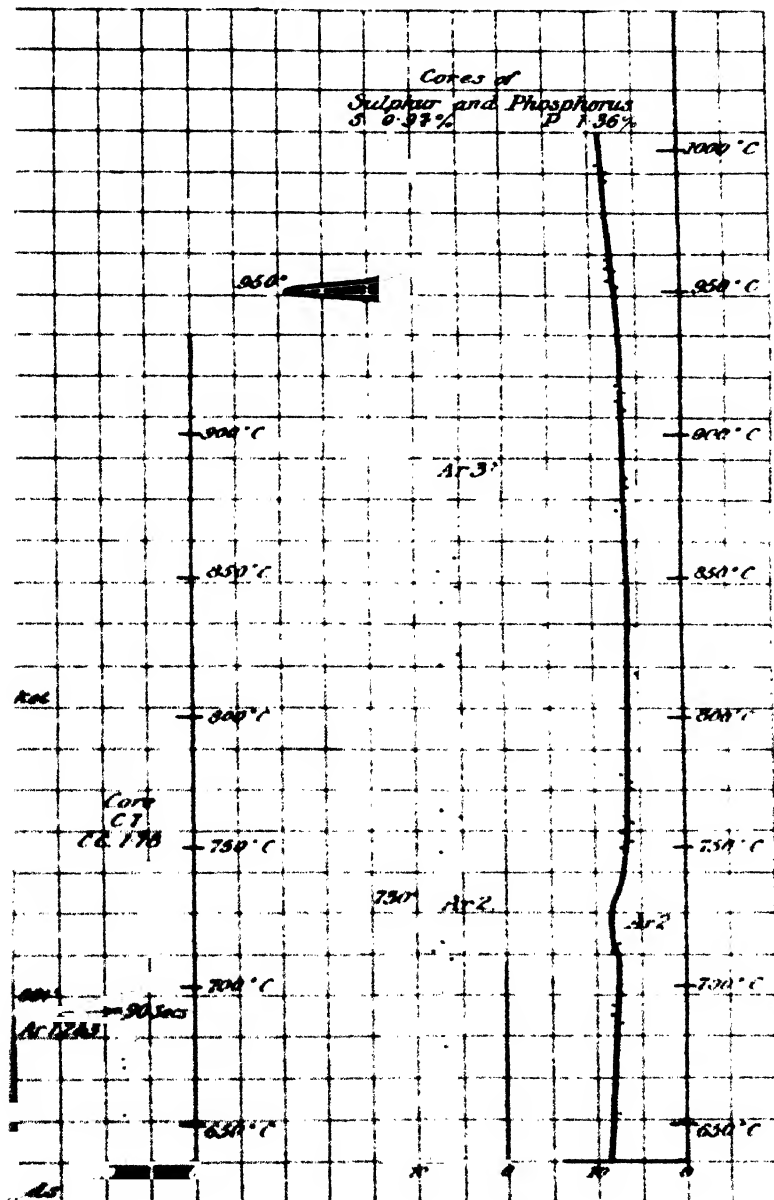
Mr. HARBORD said he should certainly like to congratulate Professor Arnold and Mr. McWilliam upon the beautiful way in which they had conducted these experiments, the great care they had taken, and the accuracy with which their experiments had been carried out. The great point about the paper was its definite facts. By showing definitely that certain things diffused under certain defined conditions, a very important fact had been established. With reference to the theories advanced, he could not quite agree on many points with the authors. They said, for instance—this was a small point, however, which really did not touch the main question—"It is well known that the phosphorus in pure cold iron exists as a definite phosphide." Now his own experience was that it existed as a very indefinite phosphide—that, at all events in steel and in wrought iron, it existed in at least three conditions. If they treated steel with hydrochloric acid, part of the phosphorus was evolved as phosphoretted hydrogen, and part of it remained in an oxidised state, and part in a partially oxidised state. He had, in conjunction with Mr. Twynam, during the last two or three years made a very large number of experiments, and had never come across any steels or wrought irons in which he did not find phosphorus existing in three distinct states. He admitted, however, that this did not touch the main point, and assuming it was proved that the phosphides present were not dissociated, whether present in one or three conditions, one must admit that they diffused as such. Passing on to the passage where the authors took the carbon solution theory into consideration, he could not agree with the arguments drawn from the analogy between the salt solution and steel. Professor Arnold took the case of brine.

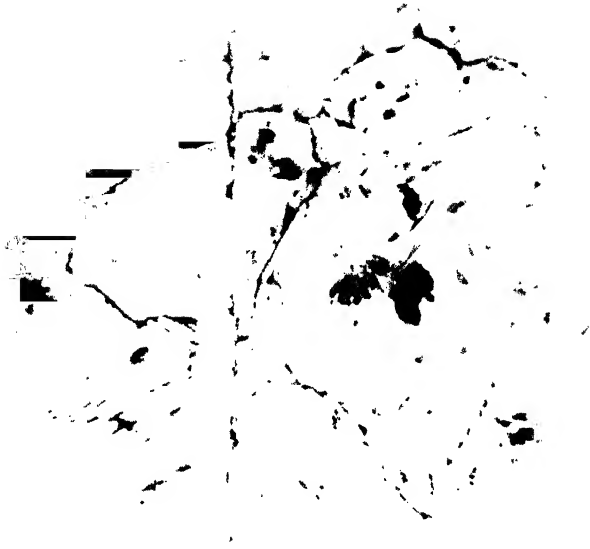
In the case of brine they had water and salt, and Professor Arnold said that in the salt solution there existed a hydrate of sodium chloride in solution which was of definite composition. He did not think physicists would admit that, and, in fact, volumes had been written for and against the very point which the authors assumed to be an established fact, viz., that a definite hydrate of sodium chloride existed as such in solution. It was true they could crystallise out a hydrate of sodium chloride of a definite composition, but under varying temperatures and with various degrees of saturations in the solution, one got a body of entirely different composition. Comparing a hot saturated solution of salt with iron solution containing carbon, they might consider the water corresponded with the iron and the carbon with the salt. If they now cooled to ordinary atmospheric temperature the salt solution, they got salt crystallising out without any water at all, but if they cooled the salt solution down to -12°C ., they got a salt combining with two molecules of water, &c. If they reduced it still further to -23°C ., they then got a definite hydrate with ten molecules of water, but it by no means followed they existed in these forms *in solution*. Now supposing they took a carbon iron alloy and cooled it down; first of all, they had carbon in some form in solution. By the hypothesis of the carbon solution theory this carbon then combined with a certain amount of iron to form Fe_3C , in the same way as the salt combined with ten molecules of water. Professor Arnold put it, if the carbon solution theory were correct, they must assume that the carbon in settling out abandoned its solvent. He (Mr. Harbord) did not consider that it abandoned its solvent, but that it combined with a part of its solution to form a definite compound, exactly as the salt did with the water. So far as the analogy of brine solution went, he could not see that there was any argument at all more in favour of the carbide theory than there was in favour of the solution theory. He thought they were in this position, that they really did not know very much about these things, and the time had not come to theorise at all, and what they wanted was to go on accumulating facts. In conclusion, he congratulated Professor Arnold and Mr. M'William upon having presented so many new facts in their paper for the consideration of metallurgists on this important subject.

PLATE XII.

ATE I.

RES AND JACKETS USED IN DIFFUSION EXPERIMENTS.





Section 4. Magnified 35 Diameters



Section 3. Magnified 35 Diameters

SULPHIDE DIFFUSION TEST-PIECE



Section before Experiment

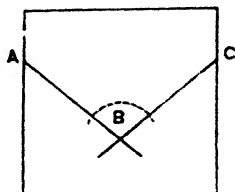


Photograph after Experiment

Dr. A. STANSFIELD said he should like to offer a few remarks on the author's paper, as it interested him, not merely as an instance of diffusion, but also in connection with its bearing on the constitution of iron and steel. He should like to congratulate Professor Arnold on having started this study of diffusion, for he was sure that it would eventually yield valuable results—results which would serve to complete the information obtained by other methods of research. Professor Arnold had raised the general question whether in white-hot steel the carbon was atomically free or whether it was combined with three atoms of iron. He did not feel at all prepared to answer that question. He only wished to point out that it was a very large question, and it was one on which whole schools of chemistry had differed. The question was as to what the exact constitution of a dissolved body is; whether, for instance, when they had copper sulphate dissolved in water it was really combined with water, and formed $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$, or whether it was, as certain schools of chemists had advanced, atomically free. He did not think that any evidence they had had so far enabled them to decide one way or the other. He had no prejudice against supposing that the carbon might be combined with at least three atoms of iron in the solution. He had intended to have alluded to the same point which Mr. Harbord had raised, namely, that there was a certain analogy between the solid solution of carbon in iron, which at high temperatures released free carbon, and at lower temperatures released Fe_3C , and solutions of salt and water which released definite hydrates at definite temperatures. In the paper Professor Arnold said: "If the solution theory be true, the following extraordinary phenomena must occur. At 1000°C . there is a solvent (iron) permeated with dissolved carbon atoms, but when the temperature is allowed to fall a little below 700°C . the dissolved free carbon abandons two-thirds of its solvent, and concentrates itself into the remaining one-third to form a saturated solution. The authors, in common with most metallurgists, reject the foregoing theory as unreasonable." Of course in that form the proposition sounded absurd. But Professor Arnold appeared to have forgotten that a solution was not a one-sided affair, but a mutual arrangement; and in the case which he considered, it was not the iron which dissolved the carbon entirely, but it might almost be

1899.—i.

described as a carbide of iron dissolving the iron. Let the following diagram represent the freezing-point curve of any ordinary solution, such as the solution of lead and tin, or the solution of salt and water:—



The line AB represented the separation of the ice, and the line BC represented the separation of the salt. The horizontal distances represented the percentage of salt, and the vertical distances represented the temperature at which the solution commenced to solidify on cooling. In the case of a solution to the left of B weak in salt, the first solid to separate out would be pure ice, and as it separated out the composition of the residual liquor changed and became richer in salt. On the other hand, in the case of a solution rich in salt, the first solid to crystallise out was salt, and the residual mother liquor changed in composition and became poorer in salt. A solution which had the composition indicated by the point B would become saturated at the same time with respect to both the ice and the salt. The result of that was that the ice crystals and the salt crystals separated out side by side in an intimate mechanical mixture. This kind of structure was represented in the case of steel by the well-known pearlite, and Mr. Stead had shown that in the case of metallic alloys they got a similar structure presented by the eutectic solution after it had solidified. Quite recently Mr. Laurie had shown that in the case of organic bodies a similar structure was obtained. The solution theory said that B was, as it were, merely an accident—that it was merely the point at which the two solubility curves crossed one another. The authors, on the other hand, in the paper maintained that the point B denoted the solidification of a definite cryo-hydrate of salt, and that the corresponding point in steel indicated the decomposition of a definite sub-carbide, Fe_{23}C . The lines AB, BC, would be merely accidental, according to this theory, being obtained by joining B to the freezing-points of the pure

constituents. There were several reasons against Professor Arnold's view. In the first place, in practically every case in which it had been studied, it had been found that the solid eutectic consisted of finely intermixed crystals of the two constituents of the solution. If it were a compound, they would expect it to solidify as a whole. If the compound were stable at a high temperature, it would probably become more stable as the temperature fell. That was one argument against its being a compound, and in favour of its being a simple solution. Again, if it were a compound it would be necessary to show, in a large number of cases, that the constitution always coincided with that of the molecular proportions. It was not sufficient to show that it coincided in one or two cases, because those one or two cases might be put down to chance. They must have a large amount of evidence upon the point. Again, there were cases in which real compounds did exist in metallic or other solutions, and in such cases it was usually found that the presence of the compound produced a sort of hump in the curve like the dotted line in the figure. They might take the case of the *Regulus of Venus*, a compound of copper and antimony. That compound had a higher melting-point than the solutions of this compound in the two respective constituents. This was another reason why it seemed to him they should not believe that these eutectics were compounds, but they should rather take them as being simply a particular case of solution in which the solution was saturated with respect to the two constituents. There was yet another argument which they might bring to bear on this subject. The lines AB and CB might be produced beyond the point B, and if they could take a solution between A and B in composition, and cool it down if possible below AB without allowing it to solidify, so that it would reach to the line CB produced, salt would then separate out at a temperature below the freezing-point of the eutectic. In some experiments recently published by Sir William Roberts-Austen, that had actually been shown to have been the case in metallic alloys, and the same had been shown by other chemists in other cases in ordinary chemistry. He should like to refer to the curve on Fig. 3 in the plates. At the recent meeting of the Institution of Mechanical Engineers, he (Dr. Stansfield) had

pointed out that the diffusion curve of iron had a close connection with the ordinary freezing-point curve, such as Sir William Roberts-Austen had shown. That was obvious, because carbon would diffuse in iron when it was in a state of solid solution in it, but not until then. There were a few points of difference, he noticed, between Professor Arnold's curve on Fig. 3 and the freezing-point curve. He should like to draw attention to these differences and to give an explanation of them. In the first case, Professor Arnold indicated that, according to the solution theory, one would expect carbon to diffuse in iron when it was heated above 700°C ., and he pointed out that it did not occur until it reached 750°C . If they took the iron that Professor Arnold first used, containing 0.05 per cent. of carbon, it could be calculated that at 700°C . only about 6 per cent. of that iron would pass into solid solution, and that 6 per cent. of iron would be distributed around the pure crystals of solid iron in such a way that it would be of very little use in aiding the diffusion of the carbon; so that it was quite reasonable to expect that in nearly pure iron they would get a very small amount of diffusion at that temperature—such a small amount that it might well escape attention. He noticed that Professor Arnold did not give any experiment with the 0.59 per cent. of carbon steel below 750°C . Perhaps if he had done so he would have found a certain amount of diffusion in it. In any case, Professor Arnold certainly showed from his figures that with the 0.59 per cent. the carbon diffused more rapidly than in the pure iron at even a higher temperature. That bore out, he thought, his (Dr. Stansfield's) views as to the solution theory. Professor Arnold drew a vertical line in the figure at 0.9 per cent., which was not very unlike the curved line shown by the ordinary solution curve, but as his vertical line rested only on one or two experiments, it was quite possible that it would be modified in course of time when Professor Arnold had perfected his experiments, and that it might fall into line with the ordinary solution curve. This part of the curve, which represented the solubility of Fe_3C , was very difficult to study by the pyrometer, and diffusion might be a useful weapon of research in determining its exact shape. He would point out that Professor

Arnold drew his horizontal line up to 2 per cent. of carbon, but the figure which he gave in the paper only appeared to show the diffusion as far as 1.2 per cent. No doubt it might occur farther on, but still he thought that from that point the line might have been dotted so as to show that the part beyond was merely hypothetical.

Professor HENRY LOUIS, on being invited by the President to speak, said he had not very much to say on the point, but if allowed, he should very much like to ask Professor Arnold a question, more for the sake of clearing his own ideas than for the purpose of adding anything to the discussion. The question was not with reference to the authors' facts, which to his mind were beautifully clear, but with regard to their theory, and especially to the question put in the paper, whether carbon could diffuse as a carbide or whether it diffused as carbon. Of Professor Arnold's four diffusible elements, nickel apparently behaved in a somewhat eccentric manner; possibly the production of nickel carbonyl under certain conditions might account for some of these peculiarities in the diffusion of the nickel. Taking the other three elements, Professor Arnold, as he understood him, admitted that carbon and sulphur might possibly diffuse as compounds which subsequently dissociated; but Professor Arnold made it a strong point, as the speaker understood it, that phosphide of iron did not dissociate, his proof of non-dissociation apparently resting upon the fact that there was no cooling-point visible in the phosphorus curve. The question he should like Professor Arnold to answer was, whether it was really impossible that any of the various complex phosphides of iron, which they knew to exist, could dissociate to a greater or less extent without cooling taking place? It seemed to him that the whole crux of the question lay in that. They knew there were cases of chemical dissociation when, instead of cooling, one actually got heating. If it was possible for a phosphide of iron to dissociate without cooling taking place, it seemed to him that Professor Arnold had not yet made out his case, because then the absence of a cooling-point in the phosphorus curve would be accounted for. If Professor Arnold preferred to say that the onus lay on the other side, and that it remained for those who maintained that

there was dissociation to prove that phosphide of iron did dissociate without any absorption of heat, he would not be disinclined to agree with him so far; but he should like to ask whether that possibility, namely, of dissociation unaccompanied by cooling, ought not to be taken into account?

Mr. SALADIN said the cooling curve of pig iron containing a high percentage of phosphorus was indicated as having a critical point between 940° and 960° C. The above temperature was also known as the melting-point of the probable phosphorus compound of the iron alloys, Fe_3P ; but with a low percentage of phosphorus the critical point was very difficult to find. Perhaps the above remarks would throw some light on the discussion about the cooling curve of the phosphorus steel.

Mr. McWILLIAM said there were a few points in the discussion which particularly struck him, and to which he would like to refer, leaving the general reply to Professor Arnold. With regard to Mr. Stead's mention of Mr. Royston's carbon diffusion paper, there was no difficulty in his mind in assuming that the iron did go back—that there was, in fact, an interpenetration. He might say that they were about to undertake some experiments to clear up that very point. The assumption also, without experimental support, that the melting-point of the phosphide of iron, though not represented on the curve, may extend from, say, 700° C. to 1000° C., is so extraordinary as not to warrant its serious consideration in this discussion. Mr. Harbord objected to the definite phosphide, but he admitted that phosphorus was present as a phosphide; but as the only point relied upon is that the phosphorus is in combination with iron, this matter does not bear on the present argument. He was very much astonished indeed to find an old Associate of the Royal School of Mines speaking in the way Mr. Harbord did about theories. There was no doubt that they must always base their theories upon the facts, and that they must always keep the facts, and not predetermined theories, before their minds; but to belittle sober and carefully considered theory was to take away the careful thought which follows experiment and to deprive them of marshals for their facts and many suggestions for future work. With

regard to Dr. Stansfield's remarks, he was afraid they were a little bit too involved to be considered at the present moment, and he would therefore like, for his own part, to consider them when they were in print. With regard to Mr. Stead's remarks on the sulphide dripping out of the ingot, that was a point which had occurred to him, but they must remember that in the cases which he and Professor Arnold had done, the sulphide was actually inside an air-tight cavity, and the only explanation which they had to put forward was that suggested, namely, that the amount of gas which would be involved in the powdered sulphide when heated up to 1000° would probably be sufficient to admit of a very considerable pressure from the inside. Whatever the explanation, however, the facts were as stated. Further, with regard to the elucidation of that particular point, one clear example of a material moving outwards under one set of circumstances and actually moving inwards under another might be seen on closer study of the action of Fe_3C when surrounded by 0.9 per cent. carbon steel, as described (see also Sections III. and IV.). In these cases the conditions were varied and carefully recorded, and it will be seen that at 850°C . the movement among the particles of cementite due to high temperature had not yet equalled the attraction between the like molecules of Fe_3C , and so the cementite had actually receded from the border towards the centre of the core, while at 960°C . this order was reversed, and the cementite moved outwards into the surrounding jacket.

Professor ARNOLD, in replying on behalf of Mr. M'William and himself, referring to Mr. Stead's remarks about the Royston experiments, said that in another part of the paper he did meet Mr. Stead's objection by proposing the very point of interpenetration. He thought Mr. Stead would admit that if they had an unsaturated steel, supposing it were a granular pearlite surrounded by ferrite at 700° , those plates disappeared, and they had *in situ* a definite composition—87 per cent. of iron and 13 per cent. of normal carbide in some form, and that remained *in situ* for perhaps 50° .

They knew that the carbon diffused, and if it were combined with carbide of iron and it diffused out of it, it was perfectly certain

that it could not diffuse out and yet leave a vacuum there. Iron must diffuse in, and therefore they had interpenetration—the iron molecules moving one way and the carbide molecules going the other way until they had established an equilibrium. With reference to the weighing of the rings, it would have been, as Mr. Stead suggested, a most interesting point; but it would be observed that with a piece specially made, so that they had absolute contact between the core and the jacket, it was a physical impossibility to carry it out under those conditions. With reference to the gold-lead plates, that too was a very interesting point which Mr. Stead had brought forward, but it was not important here. The statement that they were alternate plates of gold and lead was the suggestion, but the point was that it was an alloy, and it had the effect described. That was the important point.

The remarks of Mr. Stead and Mr. Harbord were superficial and hypercritical, it being obvious that they had not taken the trouble to read the paper carefully. A detailed study of the microsections on Plate II. would undoubtedly have altered Mr. Stead's views on interpenetration, and would also be interesting to him, as they absolutely disproved a statement so often made and enforced by him, that the structure of quenched steels contained only a single constituent, consisting of needles interlacing at an angle of 60° . Mr. Stead had failed to refer to this, and had altogether evaded discussing the vital point so clearly put forward in the paper, namely, that the pearlite areas interdiffused with the iron on heating, but reseggregated before Ar_1 on cooling.

With regard to the charge of dogmatism, to say that a paper clearly presenting the facts and discussing their bearings on two theories, and adopting the one which seemed to the authors most strongly supported by these facts was dogmatic, was clearly an abuse of words. Mr. Stead asserted that theoretically they were in a state of mental fog. Of course he had every right to claim to be best acquainted with the meteorological condition of his own mind, but he could hardly claim to speak for those who held that their mental atmosphere was tolerably clear.

Mr. Stead also claimed to bring forward a practical point which would interest manufacturers as to why sulphide did not drip out of an ingot on heating. It was not known that it

would not. If they had patience enough, they might put a bar of steel in and maintain it at a high temperature *in vacuo*, and put a dish under it and collect the sulphide, which would be a new method, perhaps, of estimating sulphur. As Mr. Stead himself had said to him, he thought they need not discuss the question of sulphides, because it was unknown ground. Sulphur probably existed in ordinary steels as sulphide of manganese. Mr. Stead and he fully agreed on that point. His practical point, however, was not so practical as he claimed it to be, inasmuch as (a) it was not usual to have ingots containing several units per cent. of sulphur, and (b) as a matter of fact, the sulphur remaining *in situ* varied from 0.03 to 0.18. The authors had yet to learn that steel containing 0.18 per cent. sulphur was a practical steel. In considering the weight of Mr. Stead's criticism, it should be borne in mind that in the opinion of many he had dismissed the patient work of Campbell with unnecessary emphasis on the result of a single casual experiment carried out under unknown conditions.

The statement was made by Mr. Harbord that the authors' analogue "begged the question." The analogue was not the authors', but the child of the President. It was also evident that Mr. Harbord did not fully understand the case of frozen brine, as he stated that the solid constituent was a compound. It was of course well known that it was a mixture of definite proportions of salt and ice, which must have resulted from the decomposition during the act of freezing of a hydrate of salt previously existing in solution. It would be interesting to know the type of fact which would satisfy Mr. Harbord, as it seemed at present that although the authors had passed seven grammes of FeS through the molecules of a wall of iron $\frac{1}{16}$ inch thick, still Mr. Harbord thought it was unreasonable theorising to say that compound molecules could traverse hot iron. It might be pointed out that Mr. Harbord's experimental acquaintance with the phenomena of diffusion in solids was even more limited than that of Mr. Stead.

Mr. Hadfield's words on the purity of the samples used, and his warning as to the danger of drawing conclusions from the behaviour of samples of unknown chemical composition, or of those containing from 0.3 to 0.5 per cent. manganese or other

constituent, and putting the results down to the effect of carbon on iron, should really be underlined in the Journal, as there was a great laxity in this matter in some researches on the influence of carbon on iron, as it was well known that Mr. Hadfield's superior limit of 0.5 per cent. might have been raised to 1.20 per cent., as in a now notorious case of recent years.

Mr. Hadfield remarked that he had switched on the telephone between Professor Campbell, Mr. M'William, and himself. As he had already said in the paper, Mr. Hadfield did more—he provided at a very critical time the sinews of war which enabled them to finish this research. With reference to the martensite, as had been pointed out in the paper, in metallurgical nomenclature, martensite was chaos. He held that a substance terminating in *ite* must have a definite composition and definite hardness within reasonable limits, and therefore he recognised as martensite a substance which was an intensely hard compound, dissolving and existing at high temperatures as Fe_{24}C before diffusion began. That brought it into line with the correspondences of mineralogy. He thought there were no real points of difference between him and Mr. Harbord on the question of phosphides. It did not matter if they had fifty phosphides: the question was did the phosphides exist as a compound? If there were fifty phosphides that would not alter the general trend of his argument in any way. Mr. Harbord brought forward the fact that there were two schools in reference to physical solution—Pickering's and Ostwald's. Pickering believed in the hydrates; Ostwald believed in dissociation. But he would point out to Mr. Harbord that the dissociation which he (Mr. Harbord) had sketched did not interfere with the question at all. Ostwald's idea was that if they put salt into water, the sodium and the chlorine decomposed and existed in the solution as free chlorine and free sodium. That being so, it was a little difficult for any one to accept that they could have free sodium in water and free chlorine without getting any of the tests. To meet that point it was said that the chemical union was dissolved, but that there was a sort of electrical policeman linking them together. So far as the sub-carbide theory was concerned, he and Mr. M'William did not care whether they were held together in a chemical union or

in an electrical union; it certainly would not alter the effect on practical metallurgy one iota.

Dr. Stansfield's remarks were exceedingly interesting, and worthy the most careful consideration, for only thus could his points be clearly understood. It would then be seen that the differences between them were really very small. Dr. Stansfield spoke of carbide of iron dissolving in iron. If Dr. Stansfield preferred to call it "solution" rather than "diffusion," the authors had no objection. The point was that they held that the evidence, carefully considered, was preponderatingly against the existence of free carbon in hot iron. With reference to the interesting point raised by Professor Louis, of course they did not want to block up the paper with a lot of data, but they had made very careful investigations on the point. The curve was a heating curve, and of course the indications were well known. The chronographic indications on heating were very much less marked than on cooling. They had taken a series of cooling curves of the phosphorus, and the line was far better than that shown in the diagram; it was, in fact, almost unbroken. But, as Professor Henry Louis had very properly argued, the evolution might be very gradual, so much so that one could not see it, which would mean that it would throw the whole line so much farther from the base line. To meet that point they had done a series, and compared them with absolutely pure iron in the same conditions of the furnace, and the lines were identical.

Dr. Stansfield was in error when he stated that they had forgotten that a solution was a mutual arrangement, for they had always given full consideration to the interdependence of the constituents and their interpenetration in cases of movement. Dr. Stansfield's view of the matter was interesting; "it might also be described as a carbide of iron dissolving the iron." Add to this that the solution in a pure iron and carbon steel was always of an absolutely definite composition, and the difference between them was very small indeed. They might assure Dr. Stansfield that the composition found was not the result of chance in two or three experiments, but had been abundantly corroborated in dozens of cases at the University College, and they were sure that Dr. Stansfield would be delighted with the wonderful delicacy of this, as shown under the microscope even

during the examination of this diffusion series, slightly over the 0·9 per cent. carbon showing cementite and very slightly under showing grains of ferrite. The authors welcomed Dr. Stansfield's complete agreement with them in the statement that, to fall in with the solution theory, the carbon ought to diffuse at 700°C ., and as his only explanation of the first two results on Table II. being against this, was an assumption of a hypothetical experimental error, supported by the assumed result of a future experiment, the results given might fairly be allowed to stand for the present. The vertical line in the diagram criticised by Dr. Stansfield was inserted on abundant evidence, for, given unlimited time, the carbon diffused at 750°C . till 0·9 per cent. was reached, and then *did not move at all* till about 900°C . was reached; and Dr. Stansfield would surely see that nothing but a vertical line at 0·9 per cent. carbon from 750°C . to 900°C . would represent these facts. The request to have the horizontal line dotted from 1·2 per cent. for the usual reasons showed that Dr. Stansfield was not thoroughly acquainted with cementation practice, which was perhaps pardonable, but also that he had not made himself master of a paper on cementation read at Stockholm, which contained the fact he desired—namely, that carbon diffused above 900°C . up to 2 per cent.

In conclusion, on behalf of his colleague and friend, Mr. McWilliam, and himself, he had to thank the Council for their invitation to give this paper to the Institute, and the Institute for the interest with which they had listened to the discussion, which he ventured to believe, when it was thought out and carefully considered, would be one of the most important that had ever taken place with reference to the history of the physics of steel.

The PRESIDENT proposed that a hearty vote of thanks be given to the authors of the paper for their valuable contribution. He said that it would at least have served to show how very ripe for discussion this vitally important question was. The discussion had been conducted with marked ability on both sides.

The motion was carried unanimously.

CORRESPONDENCE.

Mr. T. W. HOGG stated, that although somewhat outside of the boundary drawn by the President for discussion, he would like to emphasise the remark of the authors of the paper—that a full knowledge of this subject was of great importance in connection with the phenomena of segregation in steel ingots. The writer had already* pointed out that segregation of itself was quite insufficient as a direct cause of the mysterious breakages which were so irritating to manufacturers. That a core of segregated impurities could not, to any great extent, affect the strength of a bar, plate, or shaft, would be quite evident when it was remembered that a hole itself occupying the position of the segregated matter would not produce anything like such a deterioration in the strength as would be required to account for any of the sudden breakages. As an elementary illustration of this fact—if a shaft 10 inches in diameter were taken, and its strength compared with one of the same diameter, but in which a 1-inch hole was bored through the centre, it was found from the following formula—

$$\frac{\pi}{16} \frac{D^4 - d^4}{D} \div \frac{\pi}{16} D^3$$

that the reduction in strength was merely $\frac{10000-1}{10000}$, which, for all ordinary purposes, might be considered to be of no importance.

As certain cases of mysterious breakage investigated by the writer were unquestionably connected with segregation in some way, he was led to suggest in the paper already referred to, that the injury to the material was really due to a secondary effect—viz. that during the reheating of the ingot a reabsorption or diffusion of the segregated matters took place, and that this caused an alteration in the general physical constitution of the steel of such a character that it became quite rotten and unreliable, particularly at that part of the ingot where the segregated matters had principally collected.

* *Journal of the Society of Chemical Industry*, March 1893.

If this reabsorption or diffusion theory was correct, it might reasonably be concluded that the evil effects following segregation could only be thoroughly avoided by cutting off the upper portion of the ingot previous to submitting it to the reheating process. In most cases it was impracticable to do this, and one of the beneficial results which would follow a fuller investigation of this subject would be to indicate to the manufacturer the precise conditions under which he must work to prevent the objectionable segregated matters diffusing again into other parts.

Experiments upon the diffusion of sulphide of iron appeared to have given many contradictory and curious results. The writer had experimented upon the diffusion of various substances through red-hot steel. In the case of sulphide of iron this compound was fused by means of a powerful electric arc into holes previously drilled out, as shown in the following sketch, and the bars were then maintained at a red heat for about three days.

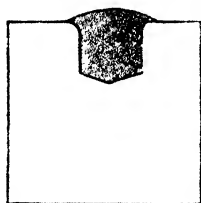


FIG. 1.

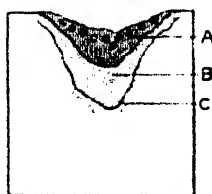


FIG. 2.

Fig. 1 shaded portion showed the sulphide of iron fused into the hole and heaped up slightly on the top.

Fig. 2 showed the result after maintaining the bar at a red heat for about three days.

In all cases tried, the sulphide had partially disappeared and the previously convex top became very much depressed, as shown in Fig. 2. After polishing and etching a section of this bar, the sulphide which remained, appeared to have separated into two layers of different character, A and B, and the distinct irregular outline C showed a margin of bright reticulating lines running into the metal. It was not unlikely that some of the variable results obtained by different experimenters had been due to the want of intimate molecular contact of the sulphide with the

metal into which it was intended to diffuse, and this method of electrically fusing in the compound might be of use to others. In certain cases, especially where the time was not prolonged, success in these experiments might be dependent upon intimate molecular contact, and it was to be expected that each compound or element would show some individual peculiarity in its mode of diffusion. The writer was inclined to reject the authors' table of classification of elements which did and did not diffuse. The subject was of sufficient importance to have these experiments repeated and extended, especially with regard to time, and when this was done it would probably be found that there were no "fixed" elements. In the case of copper and manganese the writer had in mind some experiments conducted many years ago in the cementation furnace, the results of which showed decided evidence of the diffusion of these elements, and not only this, but that manganese appeared to be slightly volatilised much below its melting-point, as a bar of pure Swedish iron carefully wrapped in asbestos paper and embedded in ferro-manganese, had its proportion of manganese slightly increased. This increase was either due to volatilised manganese or to irregular distribution in the bar: at the time, he preferred to believe it was due to the latter.

Members should feel indebted to Professor Arnold and Mr. M'William for having given a record of their valuable experiments; they suggest a large field for future research. The practical bearing of these results is of the first importance and of high scientific interest; their elucidation, however, was not likely to be made clear by treating red-hot iron or steel as a perfectly solid body, which it certainly was not.

Mr. E. H. SANITER had read with interest the paper on diffusion, and noticed one or two points which called for remark. It was of interest to compare the atomic volume of the elements with their diffusibility as given in Table I. It could not be said that any relation between the atomic volume and the diffusibility seemed to exist, but at the same time it seemed improbable that sulphur and phosphorus, with a much greater atomic volume than iron, were likely to diffuse in the free state; that, however, would not apply to carbon and nickel, which had

smaller atomic volumes than iron. With regard to the diffusion of cementite between a temperature of 850° and 950° C., it should be remembered that it was at about that temperature that Fe_3C , which had been isolated by chemical means, decomposed and liberated graphite.* That fact had, no doubt, an important bearing on the diffusion of cementite, and also on the state in which the carbon existed in iron. Before referring to the solution theory, a question of nomenclature cropped up. He referred to Professor Arnold's expression "cryocarbide." Would it not be more correct to say, if a word is to be coined, "Cryoferrite," as iron is looked upon as the solvent? The remarks in the paper were very suggestive. The fact that cementite decomposed or diffused and that graphite was liberated in supersaturated irons at high temperatures would point to the carbon being, in whole or in large part, simple solution at those temperatures; the discovery of soft austenite by Osmond also pointed in this direction. But as the temperature of a supersaturated iron fell there was a precipitation of cementite, which was recognised as a definite chemical compound, and it seemed only reasonable to suppose that at the temperature, about 850° , at which cementite began to precipitate, the saturating carbon up to 0.9 per cent. was also in the same state of combination, but dissolved in the excess of iron. Whether it had the formula Fe_{24}C or whether it should be written $\text{Fe}_3\text{C} \cdot 21\text{Fe}$ seemed somewhat immaterial, but the fact that on cooling to 650° a cryohydrate (?) was formed seemed to show a distinct resemblance between the state in which the Fe_3C up to 0.89 per cent. carbon existed in iron between 700° and 800° C. and that in which salt existed when dissolved in water, whatever that might be.

Professor ARNOLD and Mr. M'WILLIAM, in reply to the correspondence, agreed with Mr. Saniter that it was a small matter whether the material be looked upon as Fe_{24}C or $\text{Fe}_{21} \cdot \text{Fe}_3\text{C}$. His suggestion that Fe_3C decomposed in steel into iron and graphite before diffusion, as it did *per se* at about 900° C., was obviously ill founded, inasmuch as the thermal curve of super-

* *Journal of the Iron and Steel Institute*, 1897, No. II. p. 117.

saturated steels showed no perturbation whatever there, either on heating or cooling.

The PRESIDENT remarked that there was an analogous paper by Baron Jüptner von Jonstorff, a most admirable paper, and one really of very great value, but of such a length and of such a complicated nature that it would hardly be possible to discuss it. They would therefore reluctantly take it as read. The paper of Mr. Disdier was a paper of very extraordinary interest. Their visit to Bilbao was not likely to be forgotten, and they were very glad indeed to have a paper from that great metallurgical centre.

The following paper was then read :—

THE USE OF BLAST-FURNACE AND COKE-OVEN GASES.

By ENRIQUE DISDIER (BILBAO).

THE idea of utilising blast-furnace gas for driving gas-engines is of great importance to the iron industry. Although experiments up to the present have not gone beyond the limit of mere trials, it is obvious that they will form the foundation for a vast development in the near future, and unless a better system for the utilisation of this gas is known, the rate of advance on these lines may rank at least equally with the improvements that arose when blast-furnace gas was first used for raising steam. The valuable waste gas must be economised, and every endeavour should be made to reduce the loss, amounting sometimes to as much as 10 per cent., which takes place when the bell is lowered for charging the furnace.

BLAST-FURNACE GASES.

Blast-furnace gases, when compared with other gases, have several characteristic disadvantages, which may be enumerated as follows :—

1. Variable composition.
2. Low ratio of combustible to non-combustible gas.
3. Admixture of large quantities of dust, acid, and metallic vapours.
4. High percentage of moisture.

The frequent variations in the working of a blast-furnace are well known as a cause of the variation in the nature of the gas. When the furnace is working badly, the quantity and quality of the gases may become so inferior that they are insufficient even for firing the hot-blast stoves, to say nothing of raising steam for the blowing-engines and other machinery. To a great extent

these drawbacks are avoided when there are several blast-furnaces in the same plant, as it is a very rare occurrence for all the furnaces to be working badly at the same time. When there are only one or two furnaces, some means have to be kept in reserve for supplementing the gas supply, either gas-producers being used or the boilers being arranged to burn coal in case of necessity.

Coke blast-furnace gases are low in combustible constituents, being nearly at the limit which can be efficiently used in the gas-engine. Well-known experts in the manufacture and use of gas-engines do not, however, fear failure on this account, and it is only necessary to increase the size and number of the engines to obtain the requisite power, and to have recourse to a higher initial compression of the explosive mixture of gas and air in the cylinder as compared with that necessary when a better quality of gas is available. The possibility of building gas-engines of comparatively small dimensions, but capable of developing many hundreds of horse-power, has been discussed, but in this direction the industry is in its infancy. Engines of over 1000 horse-power have been built, and all the resources of science and industry are being applied for the further solution of the problem.

In view of the opinions expressed in the discussions at the meetings of the Iron and Steel Institute in May 1898, and of the Verein deutsche Eisenhüttenleute in the previous February, it would appear that dust is really the principal difficulty to be overcome in the working of gas-engines with blast-furnace gases, and this point is engaging much attention at the present time. The resistance offered by blast-furnace gases to the deposition of the dust carried in suspension justifies the fear that the dust will involve serious difficulties in the economical working and maintenance of gas-engines. Unless the dust can be reduced to a low limit without the necessity of erecting large and costly plant, it will visibly affect the advantages which are to be expected from using the gas directly in place of the circuitous course of employing it for raising steam.

Experiments carried out by the John Cockerill Company at Seraing, July 19 and 20, 1898, with a 200 horse-power gas-engine, showed 181 brake horse-power, with a consumption of 3.33 cubic metres (117.6 cubic feet) of blast-furnace gas per

horse-power hour. The gas employed was of a rather high quality, giving 981 calories per cubic metre (25 calories per cubic foot).

The next point to be determined is how long these figures will be maintained in practice, and how long the gas-engine will last in good working order in spite of the inefficient removal of dust and acid vapours from the gas. It is to be hoped that the experiments which are being carried on with such praiseworthy perseverance at some important ironworks will give a practical and satisfactory solution. Meanwhile it would be wise to proceed with extreme caution until the solution of the problem is more advanced before venturing on radical alterations of blast-furnace practice.

The quantity of moisture that the blast-furnace gases contain, although of some importance, is considered as being altogether a secondary question.

The economy that would ensue upon the direct application of blast-furnace gases to the production of power by the gas-engine is of great importance. The production of a ton of pig iron involves the consumption of a ton of coke, and one horse-power per hour may be obtained by the consumption of 4 cubic metres (141½ cubic feet) of gas. Assuming these data, then, in accordance with the opinions that have been expressed by Greiner and Lürmann, and the experiments and calculations that have been made by them, it will be found that a blast-furnace is able, by means of its waste gas, to generate nearly 2100 horse-power* for every hundred tons of pig iron produced daily, after making all due provision for heating the blast. Under the best conditions of firing the boilers with the waste gases only 579, or say 600, effective horse-power is obtained.† The difference, 1500 horse-power, is in favour of using gas-engines.

COKE-OVEN GASES.

Thus far the blast-furnace has been considered on its own merits as a source of power, but there is also its almost indispensable associate, the coke-oven, which cannot be neglected as a power-

* *Stahl und Eisen*, vol. xeviii. p. 259.

† Greiner, *Journal of the Iron and Steel Institute*, 1898, No. I.

producer. Both furnaces and ovens produce vast quantities of material, but it requires a number of ovens to feed one furnace, a number that, in the case of coke-ovens of the retort type, may be taken between twenty-five and thirty for a furnace yielding a hundred tons of pig iron daily. This subdivision of coke-oven plants into coke-ovens as units marks an important difference as regards the regularity of the gas production; for if two or three ovens are persistently out of order, or are working badly, the quantity and quality of the gas is not greatly affected. The first objection of variable composition that has been made above to blast-furnace gas for driving gas-engines does not therefore obtain as regards coke-oven gases. Furthermore, the gas is very rich in combustible constituents, and practically is the same as ordinary coal-gas. Also it carries very little or no dust, and it is absolutely free from metallic vapours, whilst the moisture is low. The conclusion naturally follows that with coke-oven gases all the difficulties at present encountered in the use of blast-furnace gases in gas-engines are solved.

All existing coke-ovens can be divided into two main groups—those in which by-products, chiefly tar and ammonia, are recovered, and those which burn their gases without recovery of any of the by-products. Both kinds of ovens, after their own heating is provided for, generally yield a surplus of heat, which is usually employed for raising steam. In well-arranged steam-generators connected with by-product ovens using coal containing 27 to 30 per cent. of volatile matter, each pound of coal charged will evaporate one pound of water under a pressure of five atmospheres.* A coke-oven plant of this design, making 100 tons of coke daily from 140 tons of coal, will thus give 140,000 kilogrammes of steam at five atmospheres pressure. If the hourly consumption per horse-power of steam at this pressure amounts to 12 kilogrammes (26·4 lbs.), this plant will give 486, or say 500, horse-power throughout the twenty-four hours, or 5 horse-power per ton of coke produced.

For heating such by-product ovens, when treating the above-mentioned variety of coal, only about 60 per cent. of the heat supplied by the whole of their gases is required, and the remaining 40 per cent. is used for raising steam. When coking coal

* *Stahl und Eisen*, vol. xcvi. p. 682.

which yields about 71 per cent. of coke and 270 cubic metres (9535 cubic feet) of gas per ton, there is produced $270 \times \frac{100}{71} = 380$ cubic metres (13,420 cubic feet) of gas per ton of coke, or 38,000 cubic metres (1,342,000 cubic feet) per hundred tons. Forty per cent. of this amount is 15,200 cubic metres (536,810 cubic feet). Dividing this by the 500 horse-power and by 24 hours, the volume of gas per horse-power hour is seen to be 1.27 cubic metres (44.85 cubic feet). In other words, a horse-power hour is obtained by the expenditure of $1.27 \times 4809 = 6107$ calories. These very advantageous figures seldom occur in practice.

If it were possible, by working ovens arranged with regenerators, to return in the gas and air used for heating them all the heat normally carried away in the product of combustion, then 40 per cent. of the gas generated might be utilised for working engines or for other purposes. Experience has shown, however, that when ovens are heated by their own gases, which have such high calorific value, it is not possible to return all this heat, and accordingly more than 60 per cent. is burnt, although the oven only requires the amount of heat given by that percentage of the gas. One consequence of this is that the heat received by the boilers comes from two sources, one being the sensible heat carried by the products of combustion of the 60 and more per cent. of the gas, and the other being that due to the combustion of the remaining quantity, which is under 40 per cent. Experience also shows that approximately 40 per cent. of the steam raised is to be attributed to the former source of heat, and 60 per cent. to the latter. Thus 200 horse-power is generated by the heat in the products of combustion, and 300 horse-power by the gas actually burnt under the boilers.

To strengthen the presentation of the case, it may be assumed that the heat corresponding to 70 per cent. of the gas is required for heating the ovens instead of 60 per cent., leaving 30 per cent. available. Thirty per cent. of 38,000 cubic metres is 11,400 cubic metres (402,610 cubic feet), and the quantity of gas available for driving engines is $11,400 \times 0.60 = 6840$ cubic metres (241,566 cubic feet). Taking the calorific value of this gas as 4809 calories per cubic metre (136

calories per cubic foot), and assuming that one horse-power is produced in the gas-engine by the expenditure of 2500 calories, then one cubic metre (35·32 cubic feet) will generate $\frac{4809}{2500} = 1·92$ horse-power hours. Thus $6840 \times 1·92 \div 24 = 547$ horse-power may be obtained from the 6840 cubic metres of gas, while the same quantity would only generate $500 \times 0·60 = 300$ horse-power if used for raising steam. The difference, 247 horse-power, is therefore in favour of the gas-engine for utilising the excess gas from such a battery of ovens making a 100 tons daily.

BLAST-FURNACE AND COKE-OVEN GASES.

During recent years many engineers have strongly advocated the installation of coke-ovens adjacent to the blast-furnaces in view of the advantages that accrue. Of these the following may be enumerated :—

1. There is complete control over the manufacture of the coke, which is so indispensable to the proper working of the furnaces.
2. Different varieties of coal may be mixed as is most expedient and economical.
3. Breakage of coke, due to handling and transport, is avoided to a considerable extent.
4. The percentage of moisture in the coke can be more easily controlled.
5. In most cases the rates for freight and handling are lower for coal than for coke.
6. Saving of fuel by the utilisation of waste coke-oven gases for raising steam.

The case may now be considered of a coke-oven and blast-furnace plant with each furnace making a hundred tons of pig iron daily, with a consumption of a ton of coke for each ton of iron made. The coke is made from coal yielding 71 per cent. of coke and 270 cubic metres (9535 cubic feet) of gas per ton. Each blast-furnace also supplies 200,000 cubic metres (7,060,000 cubic feet) of gas daily in excess of the quantity required for the hot-blast stoves.

First Method.—Under the best conditions, by firing the boilers with the coke-oven gases, $\frac{140,000}{12 \times 24} = 486$, or say 500 horse-power, are obtained, while the blast-furnace gas will give $\frac{200,000}{1.2 \times 12 \times 24} = 579$, or say 600 horse-power. The total horse-power then is 1100, though it may be said that in existing plants not even two-thirds of this power is actually obtained.

Second Method.—If now the coke-oven gases are used for raising steam, and a satisfactory solution of the problem of using blast-furnace gases in gas-engines were obtained, the results would be 500 horse-power from the ovens and $\frac{200,000}{24 \times 4} = 2083$, or say 2100 horse-power, from the blast-furnace gases. The total then becomes 2600, which exceeds that of the previous case by 1500 horse-power.

Third Method.—There is another new course open for consideration. In this the coke-ovens are heated by the blast-furnace gases, and the oven gases are used for driving gas-engines. The following table, together with those in the Appendix, gives the principal factors for the combustion of one cubic metre (35.32 cubic feet) of the gas measured at normal pressure and temperature (760 millimetres and 0° C.):—

| | Tempera- ture of Combustion. | Calories. | Air Required. | | Products of Combustion. | |
|-------------------------|------------------------------------|-----------|---------------|-----------------|----------------------------|-----------------|
| | | | Kilos. | Cubic Metres | Kilos. | Cubic Metres |
| Coke-oven gas | 2595° C. | 4800 | 6.2635 | 4.8430 | 6.7379 | 5.5239 |
| gas | 1650° C. | 880 | 0.9234 | 0.7138 | 2.1546 | 1.5660 |

| | Specific Heat. | Weight of 1 Cubic Metre. |
|---|----------------|-----------------------------|
| Unburnt coke-oven gas | 0.740 | 0.4742 |
| Unburnt blast-furnace gas | 0.264 | 1.2312 |
| Products of combustion of coke-oven gas | 0.275 | 1.2198 |
| Products of combustion of blast-furnace gas | 0.247 | 1.3758 |
| Air | 0.9375 | |

If a cubic metre of the blast-furnace gas, and also the necessary amount of air for its combustion, be heated to 750° C. before use, the sensible heat carried into the oven will be—

| | |
|-----------------------------|--|
| Blast-furnace gas | $750 \times 0.264 \times 1.2312 = 243.75$ |
| Air | $750 \times 0.2375 \times 0.9234 = 164.45$ |
| Total calories | <u>408.20</u> |

The theoretical temperature of combustion will be raised to $\frac{408.2 + 880}{0.5330} = 2417^{\circ}$ C.

The products of combustion at 1100° C. will contain $1100 \times 0.247 \times 2.1546 = 586.3$ calories, and the difference $408.2 + 880 - 586.3 = 701.9$ calories are used in heating the oven.

Supposing the coke-oven gas to be at 20° C., and the air for its combustion to be heated to 350° C., the sensible heat will similarly be—

| | |
|--------------------------|--|
| Coke-oven gas | $20 \times 0.740 \times 0.4742 = 7.02$ |
| Air | $350 \times 0.2375 \times 0.2635 = 520.65$ |
| Total calories | <u>527.67</u> |

and the theoretical temperature of combustion will be $\frac{527.67 + 4808.98}{1.8526} = 2881^{\circ}$ C.

The products of combustion at 1100° C. will contain $1100 \times 0.275 \times 6.73792 = 2037.86$ calories, and there will be left in the oven 3298.79 calories.

To take the place of a cubic metre of coke-oven gas, $3298.79 \div 701.9 = 4.7$ cubic metres (166 cubic feet) of blast-furnace gas will be required. The products of combustion will then weigh $2.1546 \times 4.7 = 10.1266$ kilogrammes (22.2785 lbs.), and will occupy a volume of $1.566 \times 4.7 = 7.3602$ cubic metres (269.93 cubic feet).

If the products of combustion of a cubic metre of the blast-furnace gas are caused to restore, through the medium of regenerators, 408.2 calories or 70 per cent. of their 586.3 calories of sensible heat, then their final temperature will be $\frac{586.3 - 408.2}{2.1546 \times 0.247} = 334^{\circ}$ C. If the products of combustion of a cubic metre of coke-oven gas give up 520.65 of their 2037.86 calories, they will retain 1517.21 calories, but in order to escape

at a temperature of 334° C., they should only retain $334 \times 6.73792 \times 0.275 = 618.77$ calories. This leaves a surplus of $1517.21 - 618.77 = 898.44$ calories, and this amount is the equivalent of $\frac{898.44}{880 - (334 \times 0.533)} = 1.25$ cubic metres (44.14 cubic feet) of blast-furnace gas. Thus the total equivalent of a cubic metre of coke-oven gas on these lines is $4.70 + 1.25 = 5.95$ cubic metres (210.13 cubic feet) of blast-furnace gas. The products of combustion of this quantity weigh 12.8199 kilogrammes (28.204 lbs.) and measure 9.3177 cubic metres (329 cubic feet). Taking the calorific values of the two gases as 4809 and 880, and assuming that one brake horse-power is produced by the expenditure of 2500 or of 3500 * calories respectively when using coke-oven and blast-furnace gas for working gas-engines, the consumption of a cubic metre of each gas will produce 1.92 and 0.252 horse-power hour. This gives a ratio of 7.62 to one, and it has been deduced that 5.95 cubic metres of blast-furnace gas were equivalent in heating power to one cubic metre of coke-oven gas. This shows a difference of $\frac{(7.62 - 5.95) 100}{5.95} = 28$ per cent. in favour of the latter. In addition, there are the facts that smaller pipes are required, that it does not need to be so highly compressed, and above all, that it does not contain dust or acid and metallic vapours.

If the foregoing data are applied to the case under consideration, the available oven gases will be $270 \times \frac{100}{71} \times 100 = 38,000$ cubic metres (1,342,000 cubic feet), which at the rate of 1.92 horse-power per hour per metre cube, will give 3040, or say 3000 horse-power. In order to replace in the coke-ovens the 70 per cent. of the heat produced by their gases, or the heat corresponding to $38,000 \times 70 = 26,600$ cubic metres (918,230 cubic feet), there must be burnt $26,600 \times 5.95 = 158,270$ cubic metres (5,589,350 cubic feet) of blast-furnace gas. This will leave a surplus of 41,730 cubic metres (1,450,558 cubic feet), or slightly over a fifth of the total, and the excess can be used in gas-engines for raising $\frac{41,730}{4 \times 24} = 435$ horse-power. The total power obtained by this method therefore is 3475, or say 3500 horse-power, showing an increase of 2400 and 900

* *Stahl und Eisen*, 1898, p. 259.

horse-power respectively over the first two methods of working. The advantages of heating the coke-ovens with blast-furnace gases, and of using the oven gases for driving gas-engines, is obvious, even if blast-furnace gases could be satisfactorily employed for the gas-engines.

There is no serious difficulty in heating coke-ovens with blast-furnace gas. It is a matter of everyday practice at all iron and steel works to heat the gases, and even at coke-ovens this is done for the air in certain cases. Also it is perfectly feasible to drive gas-engines with coke-oven gases from which the by-products have been removed, and the gas-engines used with ordinary coal-gas can be used without alteration. The dust in the blast-furnace gases is not injurious to the coke-ovens, but rather the reverse, as it tends to stop leaks in the flues of the ovens.

For driving gas-engines coke-oven gases possess many advantages over blast-furnace gases. They give over 30 per cent. more power,* with the same size of engine, and the gas mains and distributing pipes can be made very much smaller, so that the plant is rendered much cheaper. Then, again, coke-oven gas containing the light oils forms an excellent illuminant. As a heating agent for use in open-hearth and reheating furnaces it is an ideal fuel, as the time of heating is shortened, the size of the regenerators can be reduced, and the producers dispensed with. With the above-described plant making a hundred tons of pig iron daily, after allowing sufficient gas for driving the machinery, there is still a residuum of 30,000 cubic metres (1,059,500 cubic feet) of coke-oven gases daily, which may replace 9396 tons of coal† in the year, if employed for heating purposes.

CONCLUSIONS.

It has been shown that by the second method of utilising the two kinds of gas as much as 2600 horse-power may be produced, and that the gain amounts to 1500 horse-power. With a consumption of 1·5 kilogrammes (3·3 lbs.) of coal per horse-power hour, this represents a saving of 19,440 tons yearly, and at eight

g, July 8, 1898, p. 60.

† 100 cubic metres of gas = 87 kilogrammes of good heating coal.

shillings per ton the economy realised amounts to £7776. On the out-turn of 100 tons of pig iron daily this represents a reduction in the cost per ton of iron of 4s. 3·85d. By the third method the increase in power becomes 2400 horse-power, the coal saved amounts to 31,104 tons, valued at £12,441, and the cost of the pig iron is reduced by 6s. 11d. per ton. When the coke-oven gases only, without the excess of blast-furnace gas, amounting to about 21 per cent. of the production, are used in the gas-engine, the extra production of power amounts to 1900 horse-power, and the saving in coal is increased to 24,624 tons of coal annually, while the cost of the pig iron is reduced by 5s. 5·66d. per ton.

Far-reaching changes in iron and steel works practice may be expected when coke-ovens and blast-furnaces are placed side by side, forming one complete plant, and working according to the third method described above. Steam-boilers, steam-pipes, steam-engines, and gas-producers will be dispensed with, and will be replaced by a gas main through which coke-oven gases will be distributed to furnaces and gas-engines. A central station with dynamos driven by gas-engines might also distribute electricity to electromotors scattered about the works to replace several of the present steam-engines. Excellent gas-engines, rated up to 250 horse-power, and capable of being worked with coke-oven gases without modification of the ordinary form, have long been in use. Larger sized gas-engines, ranging up to about 1000 horse-power, have already been built, and their general adoption is only a matter of time.

APPENDIX.

THE following tables give the principal factors in connection with the use of blast-furnace and coke-oven gases. In all cases the weights are given in kilogrammes, and are those of the cubic metre of the gas.

*Blast-Furnace Gas.**

| | Volume. Cubic Metre. | Weight. Kilo- gramme. | Oxygen for Combustion. Kilogramme. | Products of Combustion. Kilogramme. | | | Calories Developed on Combustion. |
|------------------|----------------------------|-----------------------------|--|--|-----------------|-------------------|--|
| | | | | N. | CO ₂ | H ₂ O. | |
| CO | 0.261 | 0.3266 | 0.1866 | 0.6255 | 0.5132 | ... | 784.8 |
| CO ₂ | 0.080 | 0.1770 | ... | ... | 0.1770 | ... | ... |
| H | 0.036 | 0.0032 | 0.0256 | 0.0857 | ... | 0.0288 | 94.8 |
| N | 0.513 | 0.6439 | ... | 0.6439 | ... | ... | ... |
| H ₂ O | 0.100 | 0.0805 | ... | ... | ... | 0.0805 | ... |
| | 1.000 | 1.2312 | 0.2122 | 1.3551 | 0.6902 | 0.1093 | 879.6 |
| | | | | 2.1546 | | | |

By-product Oven Gas.†

| | Volume. Cubic Metre. | Weight. Kilo- gramme. | Oxygen for Combustion. Kilogramme. | Products of Combustion. Kilogramme. | | | Calories Developed on Combustion. |
|-----------------------------------|----------------------------|-----------------------------|--|--|-----------------|-------------------|--|
| | | | | N. | CO ₂ | H ₂ O. | |
| SO ₂ + CO ₂ | 0.020 | 0.03933 | ... | ... | 0.03933 | ... | ... |
| C ₂ H ₄ | 0.040 | 0.05907 | 0.1717 | 0.5558 | 0.15743 | 0.06435 | 559.18 |
| CO | 0.100 | 0.12513 | 0.0716 | 0.2318 | 0.19673 | ... | 300.68 |
| CH ₄ | 0.295 | 0.21107 | 0.8443 | 2.7332 | 0.58043 | 0.47493 | 2502.44 |
| H | 0.545 | 0.04882 | 0.3906 | 1.2645 | ... | 0.43942 | 1446.68 |
| | 1.000 | 0.47442 | 1.4782 | 4.7853 | 0.97392 | 0.97870 | 4808.98 |
| | | | | 6.73792 | | | |

* *Stahl und Eisen*, 1898, pp. 258-259.† *Ibid.*, 1897, p. 93.

1. The mean specific heat of the gases are—

| Of Blast-furnace Gas. | |
|-----------------------|-----------------------------------|
| CO | $= 0.3266 \times 0.2450 = 0.0800$ |
| CO ₂ | $= 0.1770 \times 0.2169 = 0.0384$ |
| H | $= 0.0032 \times 3.4090 = 0.0109$ |
| N | $= 0.6439 \times 0.2438 = 0.1570$ |
| H ₂ O | $= 0.0805 \times 0.4850 = 0.0390$ |
| | <hr/> |
| | 1.2312 0.3252 |
| Specific heat | $= \frac{0.3252}{1.2312} = 0.264$ |

| Of Coke-oven Gas. | |
|-------------------------------|-------------------------------------|
| CO ₂ | $= 0.03933 \times 0.2169 = 0.00853$ |
| C ₂ H ₄ | $= 0.05007 \times 0.4040 = 0.02023$ |
| CO | $= 0.12513 \times 0.2450 = 0.03066$ |
| CH ₄ | $= 0.21107 \times 0.5929 = 0.12514$ |
| H | $= 0.04882 \times 3.4090 = 0.16643$ |
| | <hr/> |
| | 0.47442 0.35099 |
| Specific heat | $= \frac{0.35099}{0.47442} = 0.740$ |

2. The mean specific heat of the products of combustion are—

| Of Blast-furnace Gas. | |
|-----------------------|-----------------------------------|
| N | $= 1.3551 \times 0.2438 = 0.3303$ |
| CO ₂ | $= 0.6902 \times 0.2169 = 0.1497$ |
| H ₂ O | $= 0.1093 \times 0.4850 = 0.0530$ |
| | <hr/> |
| | 2.1546 0.5330 |
| Specific heat | $= \frac{0.5330}{2.1546} = 0.247$ |

| Of Coke-oven Gas. | |
|-------------------|------------------------------------|
| N | $= 4.7853 \times 0.2438 = 1.1667$ |
| CO ₂ | $= 0.97392 \times 0.2169 = 0.2112$ |
| H ₂ O | $= 0.97870 \times 0.4850 = 0.4747$ |
| | <hr/> |
| | 6.73792 1.8526 |
| Specific heat | $= \frac{1.8526}{6.73792} = 0.275$ |

3. The air theoretically required for the combustion of a cubic metre of the gases is—

| | Kilogrammes. | Cubic Metres. |
|-------------------|--------------|---------------|
| Blast-furnace gas | 0.9234 | 0.7138 |
| Coke-oven gas | 6.2635 | 4.843 |

4. The sensible heat for each 100° C. in the products of combustion of a cubic metre of the gases are—

| | Calories. |
|-------------------|-----------|
| Blast-furnace gas | 53.30 |
| Coke-oven gas | 185.26 |

5. The theoretical temperature of combustion of a cubic metre of each gas at normal temperature and pressure (0° C. and 760 millimetres) is—

| | |
|-------------------|---|
| Blast-furnace gas | $\frac{879.6}{0.5330} = 1650^{\circ} \text{C.}$ |
| Coke-oven gas | $\frac{4808.98}{1.8526} = 2595^{\circ} \text{C.}$ |

6. The horse-power developed per cubic metre of gas is *—

| | |
|-------------------|----------------------------|
| Blast-furnace gas | $\frac{880}{3500} = 0.252$ |
| Coke-oven gas | $\frac{4809}{2500} = 1.92$ |

* *Stahl und Eisen*, 1898, p. 259.

DISCUSSION.

Mr. JAMES RILEY, Vice-President, was sure they would all echo the remarks the President had just made with regard to receiving papers from their friends in Bilbao, especially when they were papers of such interest as the one they had just listened to. They had heard something that morning about the position of facts and theory. He presumed they were in this paper in the region of theory, but he took it that there was sufficient in it to excite very considerable interest and attention and some hopes for the future. In these days the iron and steel trade should feel thankful indeed if any hopeful opening was pointed out in the future to which they could press forward. The author of the paper had undoubtedly worked out his case pretty well, but he thought before he had brought his theory into practice there would be a considerable number of difficulties to surmount. At present they were in the position of possessing facts with regard to the working of blast-furnace gases in engines; some had already been submitted to the Institute, and he was hoping that they might hear more that morning from their friends on the Continent who had been working in this direction, and from others. He thought the author might drop one of the disadvantages to which he had referred, or at all events that it might be disregarded, for the variations in the quality of the gases were not so apparent when they were used in the gas-engine as they were when used under boilers or in hot-blast stoves. At all events, he did not think these variations were so great as would be found to be the case with the gases used from the coke-ovens. Blast-furnace gases had been used in engines for something like three years; and he believed it was the case that there was no single instance known in which—no matter how poor they may have been coming from the blast-furnace, nor what may have been the conditions of the workings of the blast-furnace—they had failed to ignite and explode in the gas-engine cylinder. That was a fact which the author might take as, to some extent, meeting his remarks in regard to the variations in the quality of the

gases. He imagined that the author, before he put his theory into practice on a large scale, would find it necessary to deal with the coke-oven gases in the matter of purification, and one thing and another, to as great, if not to a greater extent, than it had been found necessary to do in connection with the gases from the blast-furnace. Without trenching farther on their time, he would simply say that personally he was grateful to Mr. Disdier for submitting his facts, and he hoped that the paper would lead to the bringing forth of some other statements from gentlemen who had experience in the use of blast-furnace gases.

Mr. HUGH SAVAGE said he had only a few remarks to make on behalf of Mr. Greiner. In the first place, it was not their intention to dispute the accuracy of Mr. Disdier's calculations in any way, or the general soundness of his views; but on one principal point they thought he went too far. He laid too much importance on the presence of dust in the blast-furnace gases, so far as their being utilised in gas-engines. If they would permit him to read the few notes which, under Mr. Greiner's direction, he had put together, perhaps he would be able to state their views pretty clearly. In the first place, there were objections to the use of blast-furnace gas in the flues of coke-ovens. Blast-furnace gas, as the members present knew, was of comparatively small calorific efficiency. The heat developed by its combustion was not very great, but to make good coke a high temperature must be maintained in the ovens. Blast-furnace gas would not generally give this temperature, and, in fact, at the ordinary atmospheric temperature would not always burn, as was sometimes found to be the case with gas-fired boilers. The deposit of dust, supposed to be so great a drawback in the case of gas-engines, was really a great drawback in the case of coke-ovens—a much greater drawback. He had positive information that a trial of the kind had been made, and with disastrous results.

At Seraing it was found necessary to clean out every four days the flues of the boilers heated by blast-furnace gas. Another point which would have to be considered was, that this dust was by no means infusible, and supposing that the high temperature required under the hearths and in the wall

passages of such ovens as were used at Seraing—Coppée or Semet-Solvay ovens—could be produced by the combustion of blast-furnace gas, a large proportion of the dust might be melted and choke the passages, besides possibly attacking the brick-work. In the cylinder of a gas-engine the high pressure and intimate mixture of the gas and the air admitted ensured combustion even in the case of very poor gas. The dangers from dust deposition were, on the other hand, much less serious than the author seemed to suppose. At Seraing practically no difficulty had been experienced for several months from this cause. They had an engine actually running at Seraing which had been running continuously for seven months in which gas used came directly from the blast-furnace, and it had never been cleaned.

In the new motors designed and constructed at Seraing, the accumulations of dust and the evils resulting therefrom, had been obviated by the use of one or two simple devices which had not been patented, and which could not be patented, but which were found to answer perfectly their object. In fact, the Société Cockerill (the works of which Mr. Greiner was manager) laid claim to having found the first satisfactory solution of the dust problem connected with the use of blast-furnace gas. As to moisture in the gas, condensation in coke columns afforded a ready remedy, but up to the present no such remedy had been required. The difference in thermal efficiency of different gases used as sources of motive power was not to their experience nearly as high as the author of the paper stated it to be. Mr. Disdier, he thought, gave 4800 calories as the result of the combustion of a cubic metre of coke-oven gas, and from 800 to 900 calories with blast-furnace gas. They happened to have a considerable number of Solvay ovens from which they recovered the by-products at Seraing; and, according to the information which was given to them by the Solvay Company—they had not made actual trial of it themselves—coke-oven gas, from which the ammonia and heavier hydrocarbons had been withdrawn, could be used in gas-engines, and gave about one horse-power for a consumption of one cubic metre per hour. The thermal efficiency of that gas was about 3000 calories. Mr. Disdier

took it at 4800, which he believed was very nearly as high as that of the ordinary gas used for lighting towns. The trials made by Mr. Witz, the celebrated gas-engine expert, last July on the 200 horse-power motor at Seraing gave a consumption of about $3\frac{1}{2}$ cubic metres of gas with a thermal efficiency of under 1000 calories. The same gentleman's experiments with ordinary town-lighting gas gave him 55 cubic metres of gas, producing by combustion 5500 calories as necessary for the development of one horse-power per hour.

Latterly, at Differdange (where the Société Cockerill had under construction a very large plant) experiments had also been made on the consumption of gas required. It had been found that 2.8 cubic metres of gas with a thermal efficiency of 1100 calories gave about one horse-power per hour. All these figures worked out in each case to a very nearly constant figure of about 3000 calories per horse-power and per hour. That might be expected from a good gas-engine almost without any regard to the quality of the gas employed, providing, of course, that the engine was made to use that gas. It was questionable, therefore, whether anything like the 30 per cent. reduction in the size of the engine claimed by the author could really be obtained by the use of coke-oven gas instead of blast-furnace gas. The 200 horse-power motor which he had mentioned had now been running for seven months without any attempt being made to clean the gas. The engine was employed for electric lighting, and the success obtained had been so very marked that it had been decided to utilise the same power for new blowing-engines, as the most immediate and practical adaptation. They had two complete plants actually being built now, one for their own works at Seraing, and another for the new works at Differdange. The new blowing-engines were expected each to do the work of one of their present type of compound blowing-engines, supplying 500 cubic metres (say 17,160 cubic feet) of air per minute, and sufficiently powerful to work a furnace giving an output of from 140 to 150 tons of Bessemer pig per twenty-four hours.

The type adopted was the single cylinder "Simplex" type, which had been patented in France by Mr. Delamare Deboutteville. The principal dimensions were a working cylinder of

the diameter of 1 metre 30 centimetres (4 feet 3 inches) in diameter and 1 metre 40 centimetres stroke (say 55 inches), with a blowing cylinder 1 metre 70 centimetres (67 inches) in diameter. These engines were intended to run at 80 revolutions per minute; the indicated horse-power was about 700; and they expected to get a return of about 550 horse-power in actually compressed air by a pressure of from 35 to 40 cubic centimetres of mercury (say from 6·7 lbs. to 7·75 lbs.) per square inch. The speed of 80 revolutions might appear high, but it was not expected to be a source of trouble, as not only were the air valves of a special type, but the inlet and outlet passages were large, so as to keep the velocity of the air below 10 metres (32 feet 8 inches) per second. In case, however, any difficulty should arise from the high speed of the motor, it was possible that instead of working the blowing cylinder direct from the gas cylinder, they might have recourse to some intermediate method, such as belt-driving or gearing. The price of each engine was about £6000. The blowing cylinder was placed horizontally, tandem fashion, behind the motor, and the whole arrangement was very compact, occupying 21 metres by 9 metres (68 feet 10 inches by 29 feet 6 inches), or much less ground space than the horizontal compound engines which they were destined to replace, in his estimation. Blast-furnace gas was growing to be regarded with much increased favour, not only in Belgium, but also in Germany. At the last meeting of the German Ironmasters at Düsseldorf, Mr. Lürrmann, who, it would be remembered, foresaw great difficulties precisely owing to the presence of dust in the gas, appeared as a complete convert to the new idea; and basing his figures on the production of pig iron for the year 1898 in Germany, estimated the possible economy for the German iron and steel trade resulting from the use of blast-furnace gas at no less than 43 million marks, or £2,150,000 yearly, which would give the meeting some idea of the importance of the question.

Mr. W. H. HEWLETT asked whether Mr. Savage could inform the meeting how at Seraing they got over the difficulty as to the dirt in the gas. It would be of very great assistance if they could ascertain that, and very important.

Mr. SAVAGE knew that it would be very important, but he did not consider himself quite at liberty to say how it was done. He had said, he thought, enough to explain that it was a very simple matter. It was a mere matter of practical construction, but it was not patented, and could not be patented, and for the present he did not think he could say any more about it.

Mr. WHITWELL asked whether the gas was washed and purified.

Mr. SAVAGE replied that the gas was not washed; it was not treated in any way. It was just as it came out of the furnace.

Mr. CHARLES WOOD said that a great many of the points to which he would have drawn attention had been answered by Mr. Savage; but he could not conceive that blast-furnace gas pure and simple, as produced in the Cleveland district, was going to be of any very great advantage without very considerable cost for extra plant for purifying and cooling the gas. In the first place, they all knew that where only one or two furnaces were at work the gases varied considerably, and would at times be useless. That would be one point of objection; the second was the enormous quantity of deposit in the gases, which, to his mind, must be taken out. There were two or three ways of getting over this: one was by washing, which would also cool at the same time; and the second was by cooling the gases by passing them through very large flues or vertical coolers, with a double object of taking out the dust and cooling; for as the temperature and the velocity of the gases declined, so did the deposit in the gas separate or fall. If they carried that practice sufficiently far, they would get a gas sufficiently pure and cool at the engine. He looked upon the question of the gas arriving at the engine in as cool and condensed a form as possible as very important. It might easily be understood that if the gases could be reduced in volume only one-half, the explosive force inside the cylinder must be doubled, and this might possibly be one of the causes of their success at Seraing. Then with different classes of ore, of coke, whether coal and coke were mixed, or whether the ore and limestone were calcined or not, the value of

the gases for a gas-engine would vary so much as in cases to be utterly useless. There was, however, no question in his mind that blast-furnace gas might be used freely in the gas-engines if the foregoing conditions were favourable. But they all knew that with gas-engines using town gas, carrying a very small amount of tar or other products in suspension, these often got deposited inside the cylinder in the shape of coke, detached pieces got underneath the valves, and the engine would cease to work economically; or, if the gas passed into the exhaust, they would not get a proper explosion, and the engine would be brought to a standstill. He looked upon that as being one of the objections to using blast-furnace gas containing a large quantity of matter. He also thought that it would be found necessary to employ a gas-holder—say equal to at least six hours' supply—so as to have a reserve in hand to start the engines with in case of the furnaces standing. This would also act as a sort of mixer, and give a more uniform quality and pressure, and also act as a further chamber for cooling and purifying the gas. There was another point of which there had not been any mention made in the paper, but which might possibly be of interest; that was that the valves for the gas-engines were chiefly made of cast iron. If blast-furnace gas was used at a high temperature, it was a well-known fact that the carbon in the gas attacked the iron very quickly. All cast iron with a bright face at a moderately high temperature was attacked by the carbon in the gases. Take a blast-furnace bell. If there was a faint flow of gas leaking past it, the iron would be dissolved away, and in a very few months they would find a very big gap or hole. It was the attack by the carbon upon the raw iron which dissolved it. The same thing would happen to the valves and cylinders unless the gas was kept cool, as it was only at certain temperatures that this action took place. It was often the case that cast iron suspended in flues near to the furnace got dissolved away and fell in pieces to the bottom of the flues from this cause. It was possible that the lubrication used in the cylinder might protect the faces from the chemical action of the gas; but this, with many other points, could only be found out by experiments on a large scale. In the paper it was mentioned that the author proposed to carry the blast-furnace gas to the coke-oven, and to

use the coke-oven gas for blast-furnace purposes. There was no question in his (Mr. Wood's) mind that if they could get the coke-oven gas for heating the stoves, and for the gas-engine, a very considerable saving might be effected; but it remained to be proved whether the gas carried from the blast-furnace to the coke-ovens without cleaning would not choke up the flues and melt the brickwork quickly in places, and thus have a material effect upon the life of the coke-oven. Certainly if ironmasters could be enabled to save 5s. 6d. or 6s. per ton upon their manufactured pig iron, he was sure that a good many of them would smack their lips and try the gas-engines. Should this question be ever worked out, there would be an enormous surplus power to spare at the furnaces which might be of great value in adjoining factories, in which case a large gas-holder would be found absolutely indispensable.

Mr. ENOCH JAMES said he had had considerable experience in dealing with blast-furnace gases and with gases from coke-ovens. He had no desire to damp the energies nor to discourage the efforts of those engaged in new developments in this direction, nor would he attempt to minimise what could be done in the near future by properly utilising these gases; but he knew something of failures that had been made in the past. These failures were due, perhaps, to the attempt made of consuming blast-furnace gases and coke-oven gases under the same boilers. About seventy coke-ovens were erected at a much higher level and at some distance away from the boilers, and all efforts made to work under these conditions proved unsuccessful. Upon removing the boilers near to the coke-ovens the results were more satisfactory, and the amount of steam raised was much increased. He would not expect success to follow attempts at conveying the gases any long distance from the coke-ovens. With regard to the utilisation of blast-furnace gases, that depended to a large extent upon the amount of dust they contained, and the variation in that was considerable, and was dependent upon the conditions under which the blast-furnaces were working, whether coal was consumed, or whether coke was the only fuel used. And until some method was devised for cleaning the gases and collecting the large amount of dust conveyed, he apprehended much diffi-

culty in connection with the use of blast-furnace gases direct in gas-engines.

Mr. G. J. WARD said that a paper, by Mr. Greiner, he thought, gave the consumption of lubricants in a small gas-engine. He did not remember the figures off-hand, but it was something like 1 cwt. or 2 cwt. per day.* He would ask the author whether he knew anything of the consumption of lubricants, and whether the difficulties due to dust in the gases were not got over in some of these cases by simply swilling the engines through with oil?

Mr. HUGH SAVAGE said they had been able to get over that difficulty continuously during seven months by merely turning in oil. A trial was made last July by Mr. Witz, a well-known specialist in the matter of gas-engines, from the account of which Mr. Ward would find the amount of oil used in the trial, which lasted forty-eight hours. He thought it would be found that the amount was not particularly large. As a matter of course, a gas-engine driven by gas containing a considerable amount of dust would require, perhaps, a little more careful oiling than if only steam, particularly damp steam at a low pressure, was used, as was the case with most steam-engines. But he had not heard that any great difficulty was met with in the consumption of oil.

CORRESPONDENCE.

Mr. W. H. BOOTH sent the following communication:—

In the manufacture of coke the output of the hydrocarbon gases is anything but regular, and it is probable that in attempting to use coke-oven gas for power purposes, the density of the gas will vary so much as to render the attempt very difficult and the running of the engines very uncertain, it being well known that it is difficult to drive large gas-engines by means of hydrocarbon gases of greatly varying quality. The explosive force at each stroke would vary in accordance with this difference.

* *Journal of the Iron and Steel Institute*, 1898, No. II. p. 134.

Further, the cooling of the gas is essential for its use in gas-engines. By cooling it, much of its richness will be lost, as the hydrocarbons will not be fixed. Certainly the gas could be treated in order to fix the hydrocarbons, but it is very doubtful if this is worth doing, in view of the pecuniary value of the products in the shape of oil and tar at present obtained. But even then coke-oven gas will compare unfavourably with blast-furnace gas. Carbonic oxide gas, of which blast-furnace gas so largely consists, is peculiarly suitable for gas-engines. *Per se* it is clean, and it burns cleanly and dry. Its combustion does not involve the thermal loss peculiar to the combustion of hydrogen, the heat of which is so largely absorbed as the latent heat of the steam produced. This is a serious loss, for the exhaust of a gas-engine is always above 100° C. in temperature. By the use of blast-furnace gas an engine will return in power within 10 per cent. of what it would return with retort gas. This point is evidently overlooked by Mr. Disdier, for he refers to the calorific value of oven-gas as being so superior, as though the superiority extended to the power produced per explosive stroke of a gas-engine. Rich gas is not used in gas-engines to give more power per stroke. True, the power developed per cubic foot used may be greater, but, as a practical fact, the rich retort gases are only admitted into the cylinder in small charges at once, and are diluted by a large volume of nitrogen—excessive air admission—and their explosion thus rendered much less violent. Blast-furnace gas contains this nitrogen already as handed over to the power engineer, and in using blast-furnace gas we do not require to add so much more diluent nitrogen. We admit more gas and less air than when using retort-gas, but we obtain practically an equal duty per stroke. The poverty of some of these gases is no bar to their employment, for a gas which will fail to ignite at atmospheric pressure will readily ignite when compressed in the cylinder of a gas-engine. The great size of the blast-furnace, its regular feeding, steady blast, and general uniformity of operation all combine to render the effluent gases very uniform in quality, and the ratio of carbonic oxide present is very constant. As has been frequently pointed out by me, the blast-furnace is an ideal gas-producer. All experience points also to the fact that even when the furnaces

are working badly, and producing gas too poor to ignite in the stoves or under the boilers, there is no trouble in the gas-engine. Explosion never fails. It is of course important to cause the blast-furnace gas to deposit its load of dust before it enters the gas cylinder. This difficulty has been thoroughly overcome. But if the gas be used for coke-oven heating, will not the calcic dust—for the dust is largely composed of lime—have a solvent and fluxing action upon the firebricks of the coke-ovens? Mr. Disdier does not discuss this point. There appears a great diversity of opinion as to the available horse-power per ton of fuel fed into a blast-furnace. In the writer's own experience it would appear that each ton of fuel per week will return ten horse-power of continuous work. With a gas coming over at the rate of 180,000 cubic feet per ton, the engine did not consume 140 feet per hour, probably not more than 124 cubic feet, and the engine was small and only partially loaded. Thus Mr. Disdier's estimates of economy must be somewhat understated. It would probably prove advantageous to work coke-ovens and blast-furnaces on one site, but if blast-furnace gas is often so poor that it will ignite neither in stoves nor under the boilers, it would be useless to endeavour to employ it in heating coke-stoves. Assuming the conditions to be present, it would seem better to use the cooled and separated coke-oven gas to work the ovens themselves, passing the surplus into the blast-furnace main for power purposes. Such a system would tend to equalise the quality of the final mixture. The present unfortunate craving of municipal authorities for manufacturing above everything electricity, and working little bits of tramways from small power stations, is altogether opposed to economy. To any thinking man it is only too obvious that sources of energy sufficient to provide a continual five or six million horse-power are being allowed to run to waste. They can only be utilised on a large scale and by the aggregation of energy and of capital. It is all so plain, that one marvels at the supineness of iron manufacturers who are allowing such a waste to continue. Mr. Disdier's carefully calculated paper is a welcome addition, even though his conclusions as to the method of using the blast-furnace gas cannot be approved. Further, blast-furnace gas cannot be employed in open-hearth and re-

heating furnaces. Its calorific capacity is too small, and sufficiently high temperatures cannot be obtained. Coke-oven gas is, as Mr. Disdier remarks, an ideal fuel for these purposes, and it is in this direction, in the saving of fuel now used for furnace-heating, that the coke-oven gas should find its opportunities of economy. But coke-ovens cannot always be placed near to blast-furnaces or to a steelworks, and they must find their own economies. In such a case the gases could be used for power purposes, and every set of coke-ovens as well as every blast-furnace ought to be a centre whence energy in the form of electricity should be distributed for lighting towns, driving tramways and railways, and pumping water, as in the South Staffordshire mines drainage scheme, which is to employ electricity, but which electricity might far better be generated by some of the blast-furnace gas now going to waste close alongside the very mines to be drained.

Mr. E. DISDIER replied briefly to the discussion, and subsequently forwarded the following full reply: Before entering into the subject, I would like to call attention to two points. The one is, that in speaking of blast-furnace gas I invariably mean, both here and in my paper, gas produced from furnaces fed entirely with coke. My calculations are based upon the figures read and published last year by Mr. Greiner at the meeting of the Iron and Steel Institute, and by Mr. Lurmann at the meeting of the Verein Deutscher Eisenhüttenleute. (The fact that the quantity of available gas from a blast-furnace may be greater or less per ton of pig iron produced in no way alters the basis of my work. The comparative calculation of the two gases which are in question remains always the same.)

In reply to Mr. James Riley, I would say that I have never maintained nor believed that the variation in the quality of the gas from blast-furnaces prevents it igniting in the gas-engine. Although the aim of blast-furnace managers is to constantly reduce the quantity of fuel consumed per ton of pig iron produced, and a reduction in fuel is equivalent to producing a less quantity of gas, the gas at the same time becoming poorer, owing to the carbonic acid resulting from the ore and the limestone, yet I do not doubt that a mixture of this gas, with the air

necessary for its combustion, would ignite in the gas-engine, provided that it be submitted to stronger compression. For me, the question would be as to the practical possibility of maintaining such compression during a long run, and also as to what irregularities of running, and what greater consumption of energy such variations might bring about in an engine constructed to be worked by means of gas of a fixed composition.

These changes in the quality of blast-furnace gas would, on the contrary, be entirely without such influence, if the gas is used for heating coke-ovens, from the moment when, making use of reheating stoves for heating up more or less the gas and the air, the power is given of replacing physically in the gas the quantity of heat which it is short of in the chemical state consequent upon its alteration.

As regards the gas from a battery of by-product recovery coke-ovens, two facts are beyond discussion, namely, its regular composition, and, since it has already undergone a purification in order to obtain the by-products, its entire fitness for employment, without any further treatment, for working engines constructed to use ordinary town-gas.

I now pass on to reply to the criticisms of Mr. Greiner, which Mr. Hugh Savage put before the Meeting.

There is no doubt that if blast-furnace gases at the ordinary atmospheric temperature were to be employed for heating coke-ovens, these gases, in some cases, would not ignite; and it is certain, also, that if they did ignite, the necessary temperature for thoroughly coking the coal would not be obtainable in the coke-ovens. But it is further an incontestable fact that if these same gases, and the air necessary for their combustion, are first brought to a high temperature by heating them by means of regenerators, they will never fail to ignite, and the heat developed by their combustion will, under these conditions, be even higher than that required for good coking.

The reason for all this is substantially the same as that underlying the fact that a poor gas requires a higher compression than a rich gas to ignite in the engine and work it economically.

I feel sure that had Mr. Greiner considered somewhat more closely the deductions which may easily be made from my paper, he would probably have omitted his observations.

Mr. Greiner has been informed that the calorific power of coke-oven gas is only 3000 calories per cubic metre. No doubt an error exists in this figure, an error which could probably be suitably explained by the local conditions to which reference was made. I look upon the Semet-Solvay oven as a good type of coke-oven, and I know that, in practical working in Germany, a gas is obtained which varies between 4000 and 5000 calories per cubic metre.* There would seem to be no good reason why at other places possessing coal which would produce this gas the ovens should not produce it, provided, of course, that the management is good. It is also not difficult to see that coke-oven gas is, and ought to be, very nearly the same as town-gas.

Mr. Greiner cites in addition some trials made by Professor Witz with blast-furnace gas from Seraing, and with town-gas of which details are not given. I do not doubt the figures given in this particular case, but in order to form an accurate comparative opinion, it is indispensable to know what type of engine, and of what power, was employed by Professor Witz in his trial with town-gas. For Mr. Greiner cannot ignore the fact that the consumption of a given gas per unit of energy obtained is very variable, according to the different types employed, and with the same type varies according to the power of the engine in which it is burnt.

In support of the above, it is only necessary to consult any trustworthy work on the construction of gas-engines, and I will cite, amongst other trials which have been carried out (which I have at hand), those of Professor O. Köhler of Dortmund, made in 1895 at Deutz, where, with an engine giving only 30 horse-power, the consumption per effective horse-power hour was only 0·48 cubic metre of gas, whilst with the same gas and with an engine of 5 horse-power of the same type, constructed at the same works, the consumption of gas could not be reduced lower than 0·55 cubic metre per horse-power hour, say 14·5 per cent. higher.†

At the present time large manufacturers of gas-engines assert that, provided the engines exceed a certain power, the horse-

* *Stahl und Eisen*, 1897, p. 93; *Ibid.*, 1895, p. 639; Durré, *Die Neuren Cokcofen*, 1892, p. 66.

† Eberli, *Kosten der Krafterzeugung*, pp. 14 and 15.

power hour is obtained with a consumption of energy below 2500 calories.

Mr. Lürrmann, who seems to be well informed on this question, gives a consumption of 2350 calories when employing a gas with a calorific power of 5224 calories per cubic metre.*

It is, moreover, easy to deduce by calculation that the consumption in calories per unit of effective mechanical energy produced by engines of the same power cannot be the same with a poor gas as with a rich one, thus resembling what is generally the case with a steam-engine working with a low or with a high initial pressure.

For, in the present case, the volume occupied by the combustible gases in a mixture of gas with the air necessary for its combustion is equal to one-sixth of the total volume when employing coke-oven gas and when blast-furnace gas is used. *Per contra*, in order to obtain the same number of calories, the respective volumes of these mixtures are in the proportion of 1 to 1.60, and the same relation is practically maintained ($1\frac{1}{5}$) by the products of their combustion. If the products of combustion escape from the gas-engine at 500° C., as is the case at Seraing,† they carry off 525 inactive calories more ‡ per every 4809 calories spent when blast-furnace gas is employed than when coke-oven gas is used. This figure represents a decrease of 11 per cent. of useful work from this cause alone.

As to the fact of the agreement between the trials made at Seraing and those at Differdange *using blast-furnace gas*, this is not by any means astonishing; on the contrary, it is what ought to be found. The figure obtained coincides nearly with others that I have had occasion to verify subsequently at other places. Although the results of isolated trials or of a relatively short practical one cannot be compared with those of long duration, I am quite prepared to accept the figure of 3000 calories per horse-power hour *for blast-furnace gas*. This figure, even if still more reduced, only increases the advantages calculated by me, always leaving per ton of pig iron produced a couple of shillings to the profit of the third method over the second.

* *Stahl und Eisen*, 1898, p. 259.

† Aimé Witz, *Journal of the Iron and Steel Institute*, 1898, No. II.

‡ $(1\frac{1}{5} \times 53 - 185) \div 5 = (5.465 \times 53 - 185) \div 5 = (290 - 185) \div 5 = 525$.

Mr. Greiner credits me with having said that one would reduce by some 30 per cent. the power of the engine. This is not accurate. What I said, and still maintain (it is also printed in my paper), is that in the same engine the power developed by the coke-oven gas is more than 30 per cent. higher than that developed by blast-furnace gas. This statement may be checked by a reference to *Engineering* of 8th July 1898, p. 60, as well as by any of the works which devote themselves to the construction of engines for rich and for poor gas.

I must pass on to consider the question of dust, which I have purposely left to the last, in order to reply at the same time both to Mr. Greiner and to Mr. Charles Wood.

Despite the statements made by the former of these two gentlemen, I must still believe, in agreement with the second, that the dust carried in the blast-furnace gas will always constitute one of the chief inconveniences which must be contended with in adopting this gas for use in engines.

This dust may be divided into three categories, viz., large, medium, and fine.

The majority, almost without exception, of those who have impartially and practically studied this question, have held that it is necessary to free the gas at least from the large and fine dust before using it in the engine, either by a dry method or by washing, or by a combination of the two means. Even in this case the influence exerted after a long period by the combination of grease with the dust still remains to be known, the quantity of dust in the gas being very variable, according to the quality and quantity of the coke employed, and with the same coke and the same ore according to the height of the blast-furnace and the pressure of blast. It goes without saying that each work stands by itself as regards the extent of the arrangements that would have to be made; but to a greater or less extent, all would require some.

Mr. Greiner has told us that at Seraing *they do not wash the gas*; but he has failed to inform us, and this would be of great interest, as to the quality and quantity of dust which the gas contains on leaving the blast-furnace, the distance that it travels, as well as the speed before arriving at the engine, and finally, although not being washed, whether the gas passes through a certain number of dry scrubbers. In reference to the

statement made by Mr. Savage for Mr. Greiner, that he had positive information that a trial of the pressure had been made with disastrous results, I cannot, in the absence of any details as to where, when, how, or in what system of a furnace the trial was made, say to what cause the failure was due. Probably, however, the blast-furnace gas was not first brought to a high temperature, nor freed from dust, by passage through reheating chambers; and if this were the case, the failure, in my opinion, was inevitable.

The most serious objection that has been made against the proposal to utilise coke-oven gas for working engines, and to employ blast-furnace gas for heating the coke-oven, consists in the fear that the heating-flues of these furnaces might be obstructed by the dust.

It is a well-known fact in practical work that, besides the means already mentioned, one of the most efficacious ways of freeing blast-furnace gas from dust consists in expansion, followed by a reduction in speed; and we have proof of this in steam-boilers and in the Cowper stoves, where the gas employed for heating them having been brought to and escaping at a temperature always higher than that which it is at on entering, deposits its dust very fully.

So in the method devised by me, a high temperature of gas before entering the coking-ovens being necessary, this dilatation is produced necessarily in the regenerators, very similar to Cowper stoves, easy to clean without interruption to the work of the whole plant. If to this be added the comparatively long distance which has to be travelled between the blast-furnaces and the coking-ovens, it is not difficult to imagine that the gas on its arrival at the coking-oven flues, will be practically free from all dust, or at least will contain so little, and that little so fine, that it will be almost totally carried away. But it may happen that this dust either settles without melting, or melts and attacks, or does not attack, the walls of the flues. To ward off the inconveniences of the first case, an exceedingly simple but expeditious and sure means of cleaning the flues has been arranged.

To overcome the drawbacks of the second case means also exist; but before determining which of them to employ, a practical trial should be made to discover whether such fusion take,

place, and if so, under what form. I hope to have the pleasure before long of giving Mr. Greiner and the other members some further information on this subject.

As regards the variations in the quantity of the gas from blast-furnaces during a given time, I attribute, like Mr. Wood, very serious importance to this point, especially when an installation of one, two, or even three furnaces is in question, when, as is natural, it is desired to profit by all the gas produced. As a means of providing against these variations, which may at times last for hours and hours, and often reduce the quantity of gas to nearly half, recourse may either be had to the employment of gasometers in which the quantity of gas necessary for several hours' work might be stored up, which method, considering the low calorific power of blast-furnace gas, would require numerous gasometers of large dimensions, or recourse might be had to spare producers, in which the gas that was lacking might be made. Now, with producers which might have to be fired up or damped down at any moment, there would be, in addition to the requisite fuel and labour, a gas of very variable composition, and when the blast-furnaces were producing an excess of gas, it would be necessary to let it escape without making any use of it.

In the method proposed by me, on the other hand, if it became necessary to store in gasometers a certain quantity of energy, sufficient for a certain number of hours, this could be obtained with at most one-fifth of the volume which would be required with blast-furnace gas, but what would be still more important, would be the fact that the battery of coke-ovens being itself a great reservoir of heat, considerably increased by additions from the heating stoves, would become, like the fly-wheel in the steam-engine, a powerful means of regulating the variations in the gas from the blast-furnaces.

In regard to the employment of the energy, I would say, in conclusion, that I share the conviction that the gas-engine is destined to be the source of motive power in the future. These engines have already replaced with advantage steam-engines in many cases, and are beginning to be introduced as blowing-engines. It may be expected that before long they will attempt to invade the rolling-mill department and find other metallurgical uses.

In the case in which a forge in a steel-works is situated near the blast-furnaces, it may easily happen that an excess of mechanical energy may be obtained for which no use can be found, whilst at the same time coal and labour are being employed in working the open-hearth and reheating furnaces for iron or steel. In the new method proposed for the utilisation of the gas, this will never be the case, for the gas from the coking ovens may be burnt as well in engines as in the furnaces mentioned, thus doing away with producers, and the cost of coal and labour.

Similarly, in certain cases it may be possible to sell the excess of gas (not freed from the heavy hydrocarbons) for lighting and other public or private purposes to a town or industry placed at a distance relatively near to blast-furnaces.

In reply to Mr. W. H. Booth, Mr. Disdier added that that gentleman ignored the fact that he was dealing with gas from by-product coke-ovens. It was not the fault of the rich gas if a quantity of air were mixed comparatively larger than that added in the case of poor gas, but rather of the gas-engine, inasmuch as a good device for mixing the gas and the air at its entrance into the engine had not yet been found. The case was similar to that in America, when it was desired to employ natural gas, which was very rich, for heating open-hearth furnaces; complete success was not attained until a method of well mixing the air and gas was devised. The uniformity in quality and quantity in blast-furnace gas existed only in Mr. Booth's imagination and in his writings, but not in practice. Indeed, the blast-furnace could not be regarded as a gas-producer in the technical sense of the word. If it were desired to add, as Mr. Booth proposed, to blast-furnace gases the surplus of the gas produced by the coke-ovens when the latter were heated by their own gas, little progress would be made. He thanked Mr. Booth for his complimentary remarks, but he did not share his opinion as to the method proposed. Time alone could prove its value.

On the motion of the PRESIDENT a cordial vote of thanks was accorded Mr. Disdier for his paper, and the following paper by Mr. Bertrand S. Summers, Chicago, Illinois, was read:—

THEORIES AND FACTS RELATING TO CAST IRON AND STEEL.

BY BERTRAND S. SUMMERS, CHICAGO, ILLINOIS.

WHILE a great deal of data have been published from the analytical side of the metallurgy of iron, there are still many anomalies and uncertainties which yet remain to be explained. As in the case of organic chemistry ultimate analysis has proved insufficient, so with iron and iron alloys it has failed to explain some of their best known properties. It may even be claimed with impunity that doubt still exists as to whether the ultimate analysis of iron is really an ultimate analysis. Such an instance, for example, was cited by Professor Ledebur some years ago, when he announced a condition of carbon similar to graphite, which was always estimated with this metalloid, to which he gave the name graphitic temper-carbon. The microscopist of recent years has sought to supply the information that ultimate analysis has failed to bring forth, and although much valuable work has been contributed by these workers, there is much of the action of the metal that is still shrouded in mystery.

In order to more clearly present the data at hand, the treatment will first be devoted to cast iron, the last part of the paper being retained for the discussion of the physics of steel.

Probably the best ideas relative to the physics of cast iron are to be obtained by examining cupola practice, and tracing products through the workshop to the uses for which they were cast. It will scarcely be necessary to enter into an elaborate discussion as to the effects of the different metalloids associated with iron in cast iron and steel. Their effects have heretofore been accurately described, and for the most part are accepted all over the world. The treatment, therefore, will be chiefly devoted to more recent ideas, and the data which tend to substantiate theories here pre-

sented. However, a more detailed delineation will be indulged in where the effects of the different metalloids on magnetic properties of iron are brought into question.

Briefly stated, the effects on the physical properties of cast iron and steel, of manganese and sulphur, and in general silicon, are well established and authenticated. Very few decisive opinions are to be found relative to the effect of phosphorus on the carbon content, the general opinion being that phosphorus has little or no effect upon the condition of the carbon, although it is stated in some text-books that it is "supposed" to prevent the formation of graphitic carbon to a slight degree. The work of the writer seems to substantiate the former view to a limiting content of somewhat over 1 per cent. of phosphorus, as irons have frequently been cast with varying amounts of phosphorus, the amounts exceeding 1 per cent. without any increment of the combined carbon being noticeable. It is with interest that the statement of G. R. Johnson before this Institute was read, and the idea of the neutral relation of phosphorus to carbon controverted. Mr. Johnson states that "phosphorus has its effect in changing graphitic into combined carbon." This view is somewhat novel to the writer, and therefore this brief discussion of the effect of phosphorus is entered into. Considerable work with cast iron and so-called semi-steel, much of which contained in the neighbourhood of 1 per cent. phosphorus, has failed to demonstrate that phosphorus has any noticeable effect on the carbon content. In this connection it seems advisable to state that the writer is now using a Southern iron in which the phosphorus content exceeds 2 per cent., and as much as 0.33–1.3 per cent. of the mixture is sometimes made of this iron. The castings are uniformly soft, and of a high graphitic content with low combined carbon, where the silicon is regulated to produce such an iron. Furthermore, the carbon content of this iron is almost entirely in the graphitic form.

The writer is in accord with most of the prominent views relating to foundry practice. However, several amendments are held to be necessary to the established view relating to the use of silicon in cupola practice. The idea is here advanced that carbon and not silicon is the controlling element, and should be the basis for planning mixtures. As a prominent feature of this

paper, the idea of the possibly important action of Professor Ledebur's graphitic temper-carbon is brought forth.

The Effect of Silicon.—Reverting again to the effect of silicon in the cupola, one cannot help but feel that there is much that is misunderstood. Silicon undoubtedly has the property of retaining the carbon in the graphitic form, but this property seems to be considerably dependent upon the range of temperature through which the silicon is allowed to act. A small increment in the content of silicon will, in nearly every case, produce a pig iron with higher graphitic carbon in proportion to the total amount of carbon present, but this effect is by no means as positive in the product of the cupola. In this connection tables are here appended of both charcoal and coke iron mixtures. The cast irons, the analyses of which form the elements of these tables, were made from practically the same pig irons, the proportions being varied.

TABLE I.

Analyses of Charcoal Iron Castings.

| | I. | II. | III. | IV. |
|----------------------------|------|------|------|------|
| Silicon | 2.20 | 2.41 | 2.66 | 2.92 |
| Graphitic carbon | 2.92 | 2.98 | 2.93 | 2.77 |
| Total carbon | 3.41 | 3.42 | 3.48 | 3.41 |

TABLE II.

Analyses of Coke Iron Castings.

| | I. | II. | III. | IV. | V. | VI. | VII. | VIII. |
|----------------------------|-------|-------|-------|------|------|------|------|-------|
| Silicon | 2.85 | 3.76 | 2.62 | 2.47 | 3.18 | 3.11 | 2.79 | 2.96 |
| Sulphur | 0.073 | 0.083 | 0.074 | | | | | |
| Manganese | 0.39 | 0.26 | 0.42 | | | | | |
| Graphitic carbon | 3.13 | 3.05 | 3.17 | 2.55 | 2.69 | 2.78 | | |
| Combined carbon | 0.18 | 0.24 | 0.08 | 0.74 | 0.51 | 0.62 | | |
| Total carbon | 3.31 | 3.29 | 3.25 | 3.29 | 3.20 | 3.20 | | |

TABLE III.

| High Carbon Charcoal Iron. | 7 per Cent. Ferro-Silicon. | Cast Iron Sprue. | Silicon. | Phosphorus. | Graphitic Carbon. | Combined Carbon. | Total Carbon. |
|--|----------------------------|------------------|----------|-------------|-------------------|------------------|---------------|
| 800 | 200 | 500 | 2.66 | | 2.90 | 0.59 | 3.49 |
| 850 | 150 | 500 | 2.68 | | 2.90 | 0.60 | 3.50 |
| 800 | 200 | 500 | 3.00 | | 2.90 | 0.40 | 3.30 |
| 850 | 150 | 500 | 2.15 | | 2.84 | 0.71 | 3.55 |
| 800 | 150 | 550 | 2.08 | | 2.97 | 0.70 | 3.67 |
| High Silicon Charcoal Iron. About 3 per Cent. Silicon. | | | | | | | |
| 600 | 400 | 500 | 1.89 | | 2.98 | 0.76 | 3.74 |
| 600 | 400 | 500 | 2.07 | | 2.98 | 0.64 | 3.62 |
| 500 | 500 | 500 | 2.40 | | 2.99 | 0.34 | 3.33 |
| 500 | 500 | 500 | 2.29 | 1.03 | 3.04 | 0.39 | 3.43 |

The first table, that of charcoal iron mixtures, seems to demonstrate this view. We have here the increment of silicon about 20 per cent., while the total carbon is nearly identical in all the four irons. Little variation in the graphite is noticeable, except that the iron having the highest silicon contains the least graphite.

In turning to the coke iron table, little relation between silicon and graphitic carbon is traceable. Having gone thus far, it seemed to introduce an element of uncertainty to consider that silicon is as effective in cupola practice as is commonly supposed.

As it was such a well-established idea that silicon is a great softening and graphitic carbon-producing element in cast iron, the work was carried further, and the analyses of the irons composing Table III. were obtained. These irons were made of a mixture of high carbon charcoal iron with high silicon coke iron, scrap, sprue, and some silicon charcoal iron being used in some cases instead of the high silicon coke iron. The object of the mixture was to produce castings of great softness that would flow exceedingly well in the moulds. The silicon was varied, and in every case the samples were taken from a casting made from the same pattern. As will be noted, while the silicon varied about 0.8 per cent. the graphitic carbon content has remained practically constant, the maximum variation being 0.14 per cent. A glance at the combined carbon content of the iron will readily show what

effect silicon has had. Where the silicon has been raised the content of total carbon immediately drops, and as there is no decrease in the graphitic carbon the iron is naturally much softer. It seems fair to state that in every case where the silicon content exceeds a certain minimum necessary to retain the normal content of graphitic carbon, no increment of the graphitic carbon can be obtained by an increase in the silicon.

Turning again to Tables I. and II., it will be seen that in no case was the variation of silicon much beyond the limits of 2 and 3 per cent. These limits are those usually adhered to in normal foundry practice, and between the limits of from 1½ to 3 per cent. the increase in silicon in normal mixtures is not conducive to the promotion of graphite. The effect, therefore, of introducing silicon into cupola practice is to lower the total carbon, and thus decrease the content of combined carbon.

There is one more idea relative to the effect of silicon, which seems to be antiquated and incorrect, and is very prevalent among the old school foundry-men on this side of the water, and that is, that by introducing or increasing the amount of ferro-silicon iron in the mixture, more scrap can be carried in the same. The scrap-carrying capacity of a mixture is obviously dependent upon the carbon content. The softening element of cast iron is graphitic carbon, and inasmuch as it is necessary to have a certain amount of total carbon present in order that graphite will be present in the casting in sufficient amount to produce the necessary softness, anything tending to decrease the carbon content tends to endanger the softness of the iron. If scrap is introduced into a mixture, the amount that can be safely added depends upon its carbon content, and the carbon content of the other ingredients of the mixture. Consequently, a scrap impoverished in carbon can only be added in such amounts as not to lower the carbon content of the mixture beyond a certain minimum. When this minimum is reached, no enrichment of the silicon will increase the scrap-carrying capacity of the mixture. This is particularly pertinent when we consider that ferro-silicon irons are themselves impoverished in carbon by virtue of their high silicon content.

Graphitic Temper Carbon.—Passing from this point, a very peculiar question may be introduced. It is well known that for

good machinery castings the silicon content should be low, and for soft-snap flask-work it should be high. In the former case the iron is dense, or close, as it is termed in the foundry. In the latter, the iron is open and somewhat spongy. When analyses are made of the two varieties of castings made with different proportions of the same brand of pig iron, a great divergence of the graphite is not noticeable. The question therefore arises, Is the constituent termed "graphite" the same in both cases? In relation to this point, the analysis of two irons with the properties and descriptions of the constituents of the mixture are interesting.

No. I.

High Carbon
Charcoal Iron.
500 lbs.

High Silicon
Charcoal Iron.
500 lbs.

Sprue.
500 lbs.

Analysis.

| Silicon. | Phosphorus. | Graphitic Carbon. | Combined Carbon. | Total Carbon. |
|----------|-------------|----------------------|---------------------|------------------|
| 2.29 | 1.03 | 3.04 | 0.39 | 3.43 |

No. II.

High Carbon
Charcoal Iron.
600 lbs.

High Silicon
Charcoal Iron.
200 lbs.

7 per Cent. Ferro-
Silicon.
200 lbs.

Sprue.
500 lbs.

Analysis.

| Silicon. | Phosphorus. | Graphitic Carbon. | Combined Carbon. | Total Carbon. |
|----------|-------------|----------------------|---------------------|------------------|
| 2.65 | ... | 3.00 | 0.41 | 3.41 |

The constituents are the same in both irons. No. I. is close and dense, and a good machinery iron, while No. II. is open and extremely spongy, and suitable for very light work. While No. I. is quite soft on exceedingly light work, it is skin hard or subject to a surface chill. The combined carbon in both cases has reached a minimum for iron in this class, and as the carbons are almost identical, it is certainly anomalous that such a difference should exist in their physical structure. The hypothesis, however, is here tentatively introduced, that in machinery iron the so-called graphite contains considerable proportions of graphitic temper carbon, and in the open porous iron for snap-flask work, the proportion of true graphite is predominant.

In discussing the possible effect of graphitic temper-carbon, one of the most interesting cases, the anomaly of which may be attributed to graphitic temper-carbon, is that of two semi-steels, the ultimate analysis of which show but slight differences. The permeability curves of these two steels comprise curve No. I. They are as radically different as two such alloys could be. These bars are both turned from lugs from castings from the same pattern. Both mixtures were as nearly identical as it was possible for them to be, the only difference being in the blast pressure. No. 479 was melted while another cupola was in blast from the same fan. No. 583 was cast in the same way from the same pattern in the same cupola, with the exception that the cupola was run with the full capacity of the fan. A glance at the curves (Plates XIX.-XX.) will show a radical difference in the magnetic properties of the metals. The physical difference is even greater. No. 479 is an open spongy iron, and turns under the tool just as cast iron would. No. 583 is a dense metal, with a steel-like lustre, and the chips are long turnings resembling those of steel. In order to better understand this peculiar difference micro-photographs of sections from these two bars were taken. In looking at these will be noticed the skeleton-like outline of the segregated carbon. The whole surface of the section seems to be covered with a fine carbonaceous dust, distributed throughout the metal, and this was particularly noticeable when the metal was turned. None of the particles are noticeable in No. 583, and none were noticed when the metal was turned. These carbonaceous particles have all the appearances of graphite, and to all intent and purpose are graphite. The clean metal occupying the interstices between the skeleton-like structure of 583, seems to be a dense homogeneous metal, and this in all probability accounts for the great strength and high permeability. It is the writer's opinion that the preponderant amount of the carbon is in the temper state in this last-named alloy.

Going from the specific to the general, it is interesting to discuss here the difference between charcoal pig iron and coke pig iron. We are all more or less familiar with the open peculiar fracture of a high carbon coke iron. It is frequently noticed that the centre of pig iron has, as it were, a nest of

graphite, which falls in considerable quantities when the metal is broken. Cavities of considerable size are not infrequent, and the metal is very open and large-grained in structure. When charcoal pig iron is examined, although the variety may contain considerably more graphitic carbon by analysis, these so-called nests of graphite are entirely absent. The grain of the iron is much smaller, and the fractures throughout more uniform. Castings from the two irons frequently show as radical a difference. There is no doubt that fine machinery iron made from charcoal pig iron is more uniform, dense, and better suited for this work than that made from coke pig iron, although the analysis in both cases may be the same. It is within the range of probability that this difference may be traced to different contents of graphitic temper-carbon which are estimated with the graphite. It is to be hoped that more work will be done along this line in the near future, and the truth or falsity of this hypothesis proved. Temper-carbon seems to be more uniformly distributed through the metal, and may be regarded as carbon in a transition state toward graphite. This is somewhat indefinite, but it is by no means certain that temper-carbon is a form of free carbon. It may perhaps be a residue of a variety of combined carbon where the same is dissolved in acids. If the above anomalies are due to the presence of temper-carbon, it is seen from the structure of the metals that it is either combined with the iron, in solution in the iron, or distributed very thoroughly through the iron. Regarding such cases as the two semi-steels referred to above, and in the light of the study of the effects on the permeability of iron of the other metalloids associated with it, it only seems fair to attribute the mystery to the carbon, and as nearly the entire content is in the so-called graphitic form, therein must lie the key, otherwise we must attribute the differences to difference in physical structure, the same being independent of the chemical constituents of the iron. This latter assumption, however, seems hardly tenable.

In recalling the peculiar physical difference between the two semi-steels described above, it may not be irrelevant here to consider the possible *role* played by graphitic temper-carbon in malleable iron castings. As stated above, a semi-steel labelled No. 583 was quite strong, and the turnings would sometimes

leave the tool in turnings 10 to 12 inches in length, which is totally different from cast iron and the semi-steel described as 479. If the hypothesis here introduced is true for these semi-steels, it is very probable that malleable iron contains considerable amounts of graphitic temper-carbon, and of course this constituent would always be reported as graphite by our present methods of analysis.

Having now briefly discussed the general physical properties in relation to the chemical composition of cast metal, it will perhaps be interesting to regard the magnetic properties in the same light.

Effect of Chemical Composition on Permeability.—Magnetism and magnetic permeability seem to be properties of the iron itself, but are influenced to a very great degree by the metalloids commonly associated with iron. It can in nearly every case be assumed that magnetism and magnetic permeability are opposed to each other, and that a state of the metal favourable to one will be unfavourable to the other.

In examining an iron for magnetic permeability, it is also quite necessary to take into consideration another property of iron, viz., hysteresis; that is, the energy lost in magnetising iron, due to the magnetic inertia of the metal, or the resistance a metal offers to magnetisation. This lost energy is usually rated in watts per pound lost under given conditions.

In general, a metal of high magnetic permeability will usually have a low hysteresis, but there seems to be little or no relation between these two properties. It is not infrequent to find a metal of high magnetic permeability and high loss by hysteresis.

These two properties of iron are what govern its adaptability for dynamo construction and similar purposes. It is with these that the metallurgist is chiefly concerned in the foundry, and as this investigation has been carried on very largely with cast metal, most of the deductions are drawn from these varieties of the metal.

In experimenting with cast iron it is exceedingly difficult to draw any trustworthy conclusions, for the reason that the large contents of metalloids make it almost impossible to trace the variations in permeability to any one, or any combinations, of the metalloids. The high percentage of graphite is particularly

obstructive in this way, and although it has but little or no chemical effect, its effect on the physical character of the iron makes it difficult to experiment under the same conditions at different times.

After endeavouring to draw some conclusions from numerous tests on cast iron, attention was devoted to making some special alloys. For this purpose wrought-iron borings were mixed with varying proportions of ferro-silicon of the following analysis:—

| Silicon. | Graphitic Carbon | Combined Carbon | Sulphur. | Phosphorus. | Manganese. |
|-----------|------------------|-----------------|-----------|-------------|------------|
| Per cent. | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. |
| 7.25 | 1.95 | 0.31 | 0.044 | 0.597 | 0.88 |

With these two ingredients a series of irons was made. They were placed in a graphite crucible, and heated in an ordinary brass foundry furnace for several hours. When the metal had come to perfect fusion, test-bars were cast and tested, and drillings from the same analysed.

These alloys were decidedly peculiar. They did not contain more than a trace of graphite, but the content of combined carbon was usually over 2 per cent. The content of silicon was varied by adding different amounts of the ferro-silicon iron.

A phosphorus iron was made by adding red phosphorus to wrought iron, and when it was desired to raise the phosphorus content, this alloy was added to the mixture of ferro-silicon and wrought iron.

Some of the more characteristic curves are here appended (Plates XIX.-XX.), in order to make the comparison more clear. This series was designated as SU series, and the curves are so denominated. The alloys were compounded by endeavouring to keep the other constituents constant while the silicon was varied. This plan was a failure, owing to the uncertainties of mixing, and the variation of carbon due to the absorption of carbon from the pot. However, by selecting the curves where the least variation is noticed, we are able to draw some deductions.

In comparing these curves let us first examine them with reference to the variation of silicon. The curve in Diagram I., marked #50-3, is a curve of very good cast iron, and serves as a means of comparison. It will be noticed that curves SU#1 and SU#2 are more nearly alike than curve SU#3. It might seem

at first sight as though this might be due to the silicon content, but a comparison with other curves will show it to be otherwise.

We would naturally expect SU#2 and SU#3 to correspond more closely than SU#1 and SU#3, as the carbon contents are more nearly alike. This difference is due probably to a difference of the state of the carbon, and variation in casting condition, which we will discuss later. If we now compare SU#2 with SU#4, we will find that their carbon contents are almost identical, while the silicon content in SU#4 is nearly double that in SU#2.

To be sure, the phosphorus varies somewhat, but this does not appear to vary the results, as we will endeavour to show later.

The curves correspond quite closely, showing that this variation in silicon could not have affected the permeability to any marked degree. Finally, if we compare curves SU#8 and SU#9, we notice that the carbon contents are about the same, but that the variation in silicon is about three-quarters of 1 per cent. The other constituents correspond quite closely, at least do not vary greatly. It would seem that if the variation of silicon had any marked effect, the variation is so marked in this case that there should be no effect traceable in the curves. The curves, however, are almost the same throughout the entire range. Also, SU#3 and SU#5 are identical, while the silicon varies considerably. These, with numerous other examples, have led to the belief that silicon has little or no direct effect upon the permeability of iron within certain limits. The same seems true in regard to phosphorus.

Comparing curve SU#2 with SU#5, we notice that there is not a great variation in anything but the phosphorus. In this there is a variation of nearly 1 per cent. On comparing the curves, we notice that while there is some variation in the curves, there is hardly what would be expected had phosphorus a marked effect on the permeability.

Again, comparing SU#8 and SU#9, we notice that the variation in phosphorus has had no more effect than the variation in silicon.

The test-bars designed to test the effect of sulphur and manganese were unfortunately so hard that they could not be turned.

It must be here noted that the comparisons above given are taken only as a general indication, and not as absolute proof. It is only in connection with other experiments that these ideas are more clearly substantiated.

It now remains to consider the relation of carbon in the above series. Unfortunately, the writer has not had opportunity to distinguish the different state of the carbon in the different test-bars, but it would seem, from a comparison of the curves, that much light would be shed upon the matter if this were done.

In a general way, it will be noticed that the test-bars containing the least carbon are a little higher, although the contrary will be noted in particular cases. Thus SU#2, containing $\frac{1}{2}$ per cent. more carbon than SU#1, is quite a little better than S#1; the same may be said of SU#3.

Having noticed the results from this series, it seemed desirable to note the effect of manganese and sulphur. In order to discover whether manganese has a marked effect on permeability, a hand-ladle was filled from a regular dynamo cast iron, and a small amount of ferro-manganese, containing about 85 per cent. of manganese, was added. A test-bar was then cast, and about the same amount of ferro-manganese again added, and another bar cast. The first bar contained 0.78 per cent. of manganese, and the second 1.76. The latter was considerably lower in permeability. It will be noted, however, that the combined carbon has been doubled by the addition of the greater quantity of manganese, and this probably accounts for the lower permeability. (See curves SU#17 and SU#18.) Manganese in all probability affects the magnetic properties through its effect on the carbon.

This effect is largely governed by the content of carbon and the content of the other elements, particularly silicon. It is safe to say, however, that the influence of manganese plays a very small part when the content is below 1 per cent. This is especially true of high carbon irons, such as cast iron. In general, what is said of manganese may be said of sulphur, as far as the indirect effect is concerned. However, a very small quantity of sulphur has a very powerful effect; this is especially true in low carbon irons.

The experiments with sulphur were mostly carried on with a

semi-steel, containing from 40 to 50 per cent. of steel rail scrap, and having a total carbon content of about 2 per cent., most of which was in the graphite state. In these irons, when the sulphur rose much over one-tenth of 1 per cent., it was nearing the danger limit, while 0.13 per cent. was fixed as the maximum for any metal of this composition, where even moderate results were expected. It must be noted, however, that a soft graphitic carbon iron could carry this content without much detriment to its permeability. If the sulphur was increased in these high carbon irons, a very bad effect is noticeable.

The effect of sulphur is undoubtedly indirect, and affects the permeability through its power of promoting combined carbon. One of the test-bars of semi-steel, containing about 0.15 per cent. of sulphur, was so white and hard that it could not be turned, although the other constituents were normal, with the exception of the high content of combined carbon.

If we return to our consideration of the effect of silicon on the magnetic properties of iron alloys, and consider another alloy of iron, we will find our deduction from the first series confirmed. The alloy selected for these tests was the semi-steel above mentioned, except that the sulphur content was normal.

It will be noted in the accompanying curve the relative position of the metal to cast iron and cast steel. With this alloy the silicon varied about $\frac{1}{3}$ of 1 per cent., and in some cases nearly 1 per cent., without any appreciable effect. A variation of five-tenths of 1 per cent. produced no effect whatever upon the permeability. The silicon in this alloy is always kept above 3.75 per cent., consequently is always so high that the change in the content could scarcely affect the state of the carbon. However, it was found that the content of silicon had a marked effect on the hysteresis, the loss by hysteresis being very much less when the silicon was high. A variation above 3.75 per cent. had an effect on the hysteresis where none was noticeable on the permeability. It would seem fair to presume that silicon has no direct effect on permeability, and above the limit necessary for holding the carbon in the graphite state it is doubtful if it has any effect. This is also probably true in the irons containing no graphite, but there would undoubtedly be a limit in this case.

In the same way, phosphorus can vary greatly in this metal

without any noticeable effect. Within the limits that have been experimented with, nothing has been noticed that would lead one to think that phosphorus has any effect on permeability or hysteresis. This limit is over 1 per cent., and covers the range that would be met with in commercial work.

The carbon is undoubtedly the chief factor in the chemical effect on permeability and hysteresis. Practically the same effects were noticed in the semi-steel as in the pot-irons previously mentioned. In general, a low content of combined carbon indicates high permeability and low hysteresis. It is often noticeable, however, as in the case of the pot-irons, that an iron containing more combined carbon than another would have a higher permeability. To discard physical effects, this is readily accounted for by the different state of the carbon.

It has occurred to the writer that there was some form of combined carbon that varied in irons high in combined carbon, and the permeability was more affected by the content of this form of carbon than by the total content of combined or graphitic carbon. This form of carbon seems to be that which Professor Ledebur calls hardening carbon, and is probably the complex crystalline mass isolated by the microscopist under the name of Martensite. Although not having opportunity to investigate this question further, from the meagre data at hand on this phase of the question, it would seem that this is the state of the carbon having the most influence in the different varieties of iron in which permeability and hysteresis are important. This is offered merely as a suggestion, and the writer has hopes of investigating the matter further.

While graphite appears in cast iron as an inert body relating to magnetic properties, such cases as that above mentioned are by no means infrequent with semi-steel. This cannot help but lead one to think that graphite is quite a factor where it is the predominating form of carbon in metals such as semi-steel. In these alloys the carbon may be said to be in a condition more sensitive to change. With such a high silicon content, one would naturally expect the predominance of graphite, but in some cases the combined carbon has amounted to nearly one-half the total carbon, which made the castings useless for magnetic purposes. Possibly in cast iron the content of graphite

is so high that a variation in the amount or the condition of the same produces relatively no effect in the permeability curve; but in the semi-steel castings, where the permeability may vary 100 per cent., any change in the carbon is made naturally more apparent than in the former case. With steel these general effects should also hold, although the metalloids are present in such minute amounts, and the variation in the permeability is so slight, it is difficult to state anything positively.

The physical state of the metal is equally or more potent in its effect on the magnetic properties of iron, and it is this effect that makes deductions from experiments on chemical effects more or less general. An almost carbonless iron will often be found of low permeability and high hysteresis in comparison with its class. After it is annealed, it will sometimes give results very much better than its class. This seems to be due to an internal stress, which has resulted from some heat treatment, and inasmuch as the specimen is nearly pure iron, it must be purely physical. This might be attributed to an allotropic state of iron similar to that proposed by Mr. F. Osmond of France; but whatever be the facts, the physical condition of the metal must ever play an important part in calculations of this kind. It does not, however, make the chemical study useless. It is often surprising to note how closely one can figure from chemical results, and the chemical study of these irons has been of high commercial importance where it has been pursued.

Magnetic Retentivity or Permanent Magnetism.—Little can be said regarding the magnetic retentivity of cast iron. While combined carbon seems to be an important constituent, it by no means follows that the cast iron that contains the greatest amount of combined carbon will have the greatest magnetic retentivity. In this connection, I here append a micro-photograph of a permanent magnet made of cast iron, together with a photograph of ordinary soft grade magnetically permeable cast iron, and a few of the special pot-irons mentioned above. While there is nothing of importance to be gleaned from examining these, a comparison of the difference of structure is very interesting, particularly when they are compared with the semi-steel, which has about 50 per cent. better magnetic permeability than the cast iron. These special pot-irons have practically no graphitic carbon, and contain an extremely high content of

combined carbon, but their permeability is about 30 per cent. better than ordinary cast iron, and they have practically no permanent magnetism.

Turning to Table IV., it will be seen that, although the combined carbon of the cast iron permanent magnet is very much less, its magnetic retentivity is very much more than the pot-irons. This is probably due to the fact that the cast iron permanent magnet has a proportionately high content of hardening carbon, while the pot-irons are poor in this constituent. The micro-photographs seem to indicate that almost the entire content of the pot-irons is in the carbide state. It is interesting to note that, in examining the structure of the cast iron permanent magnet, the structure of carbide carbon is noticeable, although on a much smaller scale than in the former.

TABLE IV.—*Cast Iron Permanent Magnet Typical Analysis.*

| Silicon. | Sulphur. | Phosphorus. | Manganese. | Graphitic Carbon. | Combined Carbon. | Total Carbon. |
|------------------------------|----------|-------------|------------|-------------------|------------------|---------------|
| 2.83 | 0.127 | 0.502 | 0.370 | 2.14 | 0.55 | 2.69 |
| About 2000 lines per sq. cm. | | | | | | |

Pot-Iron Typical Analysis.

| Silicon. | Sulphur. | Phosphorus. | Manganese. | Graphitic Carbon. | Combined Carbon. |
|---|----------|-------------|------------|-------------------|------------------|
| 2.54 | 0.052 | 1.139 | 0.698 | trace | 1.74 |
| Very poor retentively, good permeability. | | | | | |

The Effect of Manganese.—The constituent which effects magnetic retentivity to the most marked degree, both in cast metals and in steel, is manganese. To trace the effect of this metal on iron alloys, different amounts of an 85 per cent. ferro-manganese were introduced into a ladle of the high permeability semi-steel similar to that above described, and the same magnetised, and the total lines of force emanating from bars of the same size determined. In every case manganese was seen to increase the retentivity to a marked degree. The following table shows this very clearly.

TABLE V.—*Semi-Steel.*

| Magnetic Lines before Addition of Ferro-Manganese. | After Addition. | |
|---|-----------------|---------|
| | No. I. | No. II. |
| 565 | 1775 | 1740 |
| 344 | 1450 | 1570 |

Magnetic Retentivity of Steel.—In selecting steel for magnetic purposes, although the retentivity is the main point in view, the

physical qualities of the metal must be taken into consideration. The steel is usually bent cold, which requires a metal of considerable toughness, and must also stand a high hardening temperature without cracking. It is therefore a mean between maximum retentivity and maximum working qualities that is sought for. A better magnet might be obtained by increasing the carbon and manganese, but the metal would be so brittle, after certain contents were reached, that it would be of very little commercial use. It is a well-known fact that high contents of manganese, occurring simultaneously with high contents of carbon, have this effect, and a steel low in manganese will stand a higher carbon content without becoming brittle, assuming both the sulphur and phosphorus far below the danger limit.

Regarding the effect of manganese on the physical properties of the metal, it is but natural that we should expect a marked effect on the magnetic properties, and this experiment shows to be true.

In collecting data of this kind, difficulty is usually experienced on account of the change in magnetic retentivity due to the temperature of hardening, also of slight shock after magnetisation; but barring minor changes, the results, with but few exceptions, show clearly the effect of manganese on magnetic retentivity.

TABLE VI.—*Analysis showing Magnetic Lines per Sq. Cm., Average of Six Magnets for each Value.*

| | per Sq. Cm. | | Sulphur. | Phosphorus. | Manganese. | Carbon. |
|-----|---------------|-------|----------|-------------|------------|---------|
| 1 | 4158 | 0.160 | ... | 0.068 | 0.27 | 0.66 |
| 2 | 5862 | 0.204 | ... | 0.069 | 0.77 | 0.61 |
| 3 | 5945 | 0.122 | ... | 0.126 | 0.64 | 0.56 |
| 4 | 5840 | 0.101 | 0.038 | 0.100 | 0.90 | 0.53 |
| 5 | 5545 | 0.131 | 0.040 | 0.078 | 0.81 | 0.53 |
| 6 | 5759 | 0.063 | 0.037 | 0.111 | 0.87 | 0.57 |
| 7 | 5400 | 0.120 | 0.042 | ... | 0.74 | 0.56 |
| 8 | 3860 | 0.110 | 0.035 | ... | 0.38 | 0.72 |
| 9 | 5400 | 0.170 | 0.039 | 0.107 | 0.74 | 0.52 |
| 10 | 5502 | 0.140 | 0.038 | 0.120 | 0.73 | 0.51 |
| 11 | 5348 | 0.113 | 0.022 | 0.137 | 0.77 | 0.51 |
| 12 | 4842 | 0.122 | 0.009 | ... | 0.79 | 0.51 |
| ... | Higher Heat. | ... | ... | ... | ... | ... |
| ... | 5063 | ... | ... | ... | ... | ... |
| ... | Highest Heat. | ... | ... | ... | ... | ... |
| ... | 5352 | ... | ... | ... | ... | ... |

TABLE VII.—*Showing Effect of Standing without Armatures on Magnetic Retentivity.*

| Dates. | Lines per Sq. Cm. | Silicon. | Sulphur. | Phosphorus. | Manganese. | Carbon. |
|---------|-----------------------------|----------|------------------------|-------------|------------|---------|
| 1898. | | | | | | |
| June 18 | 6411 | 0.173 | ... | ... | 0.74 | 0.52 |
| July 5 | 4415 | ... | ... | ... | ... | ... |
| | | | Loss 31 per cent. | | | |
| June 27 | High Heat. 5352 | ... | ... | ... | ... | ... |
| July 7 | 4117 | ... | ... | ... | ... | ... |
| | | | Loss 23 per cent. | | | |
| June 27 | Extra High Heat. 5406 | ... | ... | ... | ... | ... |
| July 7 | 4360 | ... | ... | ... | ... | ... |
| | | | Loss 19.3 per cent. | | | |
| Aug. 8 | 5348 | 0.113 | 0.022 | 0.137 | 0.77 | 0.51 |
| Aug. 22 | 3725 | ... | ... | ... | ... | ... |
| | | | Loss 30 per cent. | | | |
| Oct. 3 | 5063 | 0.133 | 0.009 | ... | 0.79 | 0.51 |
| Oct. 10 | 4403 | ... | ... | ... | ... | ... |
| | | | Loss 13 per cent. | | | |

TABLE VIII.—*Showing Effect of Temperature of Hardening on Magnetic Retentivity.*

| Lines per Sq. Cm. | | | |
|----------------------|--------------------|-----------------------|-----------------|
| Medium Heat. 5166 | High Heat. 5352 | Highest Heat. 5406 | |
| Analysis. | | | |
| Silicon. 0.173 | Manganese. 0.74 | Total Carbon. 0.52 | |
| Lines per Sq. Cm. | | | |
| Medium Heat. 4842 | High Heat. 5063 | Highest Heat. 5352 | |
| Analysis. | | | |
| Silicon. 0.122 | Sulphur. 0.009 | Manganese. 0.79 | Carbon. 0.51 |

It is a curious fact that the steel in Table VI., having the highest carbon content, has the lowest magnetic strength. We

notice, however, that it is considerably below the remainder of the steels in manganese, with but one exception. The next lowest in magnetic strength in this table brings this fact prominently to our attention. In No. 1, containing 0.27 per cent. manganese and 0.66 per cent. carbon, 4158 lines are reported per sq. cm. In No. 8, although the carbon has reached about its maximum for steel intended for magnets, being 0.72 per cent., the magnetic force is the lowest of any in the table, due in all probability to the fact that a steel of moderate carbon content and high manganese makes excellent magnets, while a high carbon steel with low manganese makes rather a poor magnet.

When the carbon and manganese are of average content for this grade of steel, say between 0.60 per cent. and 0.70 per cent., good magnets may be expected, but considerable loss is liable to occur in working them. The writer is accustomed to specify the carbon between 0.50 per cent. and 0.56 per cent., manganese 0.70 per cent. and 0.80 per cent., sulphur not to exceed 0.05 per cent., phosphorus not to exceed 0.10 per cent., and silicon not to exceed 0.15 per cent. This steel gives very good satisfaction in practical use. The sulphur and phosphorus are limited on account of their effect on the working qualities of the steel. Relative to silicon it is probably true that ordinary contents of silicon, usually found in magnet steel, have practically no effect on magnetic retentivity. If this metalloid occurred in too high a content, it would seem, judging from its effect on permeability, that it would tend to weaken the magnet.

Regarding the life of a magnet without its armature, there does not seem to be much difference. In the table here appended, the data are rather meagre. Unfortunately, the tests are collected from numerous records, and no standard time element is taken into consideration; but figuring the loss proportionately on a common time basis, it will be seen that very little difference is noticeable.

Relative to the effect of the temperature of hardening on the magnetism, the common belief is certainly true, that the higher the temperature at which the magnet is hardened, the more magnetism is found. Isolated cases are sometimes found where this is apparently contradicted, but further examination will usually prove this to be an error. Repeated experiments with

practical working seem to demonstrate that high heats are preferable. In this particular a moderate carbon and high manganese steel is found to excel. A higher hardening temperature can be utilised without great loss by breakage. This is not the case when the carbon content is high, or when carbon and manganese both exceed something like 0.60 per cent.

Deductions from the Effect of Manganese upon the Magnetic Properties of Iron.—The magnetic properties of iron, both permeability and retentivity, are regarded as properties relating to iron and carbon and iron respectively, and the effect of manganese is certainly worthy of attention. Permeability seems to be a property of iron itself, and is not notably affected by any of the metalloids usually associated with iron, other than carbon and manganese. Carbon is usually considered essential for permanent magnets, but I am unaware that manganese is regarded in this light. It seems but a fair assumption that hardening carbon is the state of the carbon favourable to permanent magnetism, and few metallurgists will dispute the fact that the carbon is in combination in this state. If, therefore, the carbon in combination has such a marked effect upon magnetism, and only when it is combined, why is it not legitimate to assume manganese in the combined form? There is little doubt of the powerful effect of manganese upon the magnetic properties of iron, and as metallic manganese possesses practically no noticeable magnetism, is it not peculiar that manganese alloyed with iron should have the effect of making iron retain magnetism? It seems, therefore, no more than legitimate to conclude that manganese in steel is in the combined form. Now, as the effect on the permanent magnetism of steel of manganese and carbon bear some mutual relations, we would naturally look for a combination between these two elements. It hardly seems equitable to argue that manganese is simply in the alloyed form. There is no reason why manganese cannot be combined in steel, and its effect, both on the physical and magnetic properties, tends to bear this assumption out. I think Mr. R. A. Hadfield is arguing along the right lines, and certainly the effect of manganese in magnet steel has not satisfactorily been explained on any other assumption.

It is to be regretted that the data here appended are not

more complete, but such data are rather difficult to obtain. They, however, have the advantage of representing tests on a commercial scale. The permeability bars, for the most part cast as lugs on large dynamo electric machinery castings, and the magnets taken from carload lots and average results from several magnets of each batch, make up the tables here given.

In this connection, I wish to acknowledge the help I have received from Mr. Herbert R. Kingman and Mr. George D. Hale in the electrical testing, and Mr. E. J. Ericson in the chemical examination, whose excellent help has greatly aided me in collecting such information as this paper presents.

DISCUSSION.

Mr. R. A. HADFIELD, Member of Council, said they were very much indebted to Mr. Summers for bringing a new question before them. He believed that there was amongst electricians a demand for material of high permeability and of somewhat cheaper cost, and he thought Mr. Summers had been working in that direction. There was a question raised in the paper as to whether the manganese present was combined with the iron. Speaking for himself, he considered that the combination in question was a carbide of manganese or a double carbide of iron and manganese. With Mr. Summers, he thought there was no doubt about the carbide of manganese being objectionable in material required to be of high permeability.

Mr. W. M. MORDEY was glad the Institute had before it a paper dealing with some aspects of the magnetic condition of iron, as this was a subject of growing importance in electrical applications. The observed non-effect of silicon on the permeability might be studied in connection with a purpose for which it had been claimed certain amounts of silicon were of use, that is, in the prevention of magnetic ageing or fatigue in iron. If only because they were work in a comparatively unexplored field, the author's experiments on cast iron permanent magnets were of interest. Permanent magnets of steel, used in the beginning for the field magnets of generators, had given place to the more permeable soft iron and mild steel, because of the reduction of size or increase in power; this in spite of the constant loss in magnetising such magnets. The author did not seem to have succeeded in getting magnetisation dense enough to be of practical use, but it was to be hoped he would not be discouraged from further investigation in that direction. Another point of very great interest might be mentioned—the relation between electrical resistance and magnetic permeability in iron. Many years ago Professor Hughes showed a singularly close inverse relation in these properties in wrought iron. Curiously, in cast iron this relation was very different to what it was in wrought

iron, the electrical resistance of cast iron being about ten times that of wrought iron, although the magnetic permeability was only about half at ordinary working densities. The electric resistance of iron was often of considerably greater importance than the quality of low hysteresis to which great attention had been paid. It was of importance on account of the eddy losses in electrical apparatus and the losses due to resistance in the steel rails of tramways. High resistance was wanted for one purpose, low resistance for another.

Mr. BERTRAND S. SUMMERS sent the following reply to the discussion on his paper:—

There is little one can add to the above discussion. The general scope of the paper was an endeavour to bring out some ideas in recent foundry practice, and to produce some facts relating to the effect on the magnetic properties of iron of the metalloids associated with it.

For some time past the author has been convinced that the control of commercial foundry practice by the effect of silicon was impractical, and that the general effect of silicon in cast iron was somewhat exaggerated. This point is at present being discussed with considerable interest in the United States, and it is hoped that the ideas presented in the paper may elicit further discussion.

The writer has read Mr. Morley's excellent remarks with much interest, and is in full accord with the ideas expressed. The aim of the paper was not so much heralding new discoveries, as to make deductions from the effect of the chemical constituents of steel or iron on the magnetic properties of the same.

While a metal of high permeability is a great desideratum, the cost and inconvenience necessary to its production preclude its use at the present time in considerable of the dynamo-electric machinery now manufactured. For this reason, a metal of higher permeability than cast iron, which may be produced with equal facility and cost, is frequently of use for dynamo castings. A metal of this description is often used with soft iron pole pieces cast in it. It was the commercial adaptation of such a metal, commonly called semi-steel, that led to the study of the effects outlined above.

It is certainly to be hoped that such a metal as Mr. Mordey described may be discovered in the near future, and one cannot help thinking that the study of the influences governing the magnetic properties will hasten the discovery of such metal. The metalloids associated with iron occur in such small proportions in soft irons that it is difficult to make any logical deductions. For this reason, investigation has been carried on principally with cast iron and semi-steel, where the effects are more exaggerated, but there is every reason to suppose that these metals are but of transitory use, and will give way in time to the softer varieties of iron which have so much higher magnetic permeability.

On the motion of the PRESIDENT, a cordial vote of thanks was accorded to the author for his paper.

CORRESPONDENCE.

Mr. J. E. STEAD, Member of Council, wrote:—The fact referred to by Mr. Summers, that the so-called ultimate analyses of cast irons have failed to explain some of their best known properties, was well known to him; but, notwithstanding, he was equally well aware that it was possible, under given conditions by synthesis, provided the elements were available, to produce cast iron of constant or practically constant physical properties.

The structure of the cold metal was dependent on many conditions, and differences in structure were coincident with variations in properties.

Given a metal of a definite composition, the conditions of melting, the size and temperature of the mould, the temperature of the metal, and the rate at which it is cooled after casting, all had an influence in causing variations in the final properties. Analyses alone did not enable them to explain these differences.

A coarse open metal, with large and thick plates of graphite cutting up the mass in all directions, was much weaker than the

metal with the graphite in finer plates, or, if it existed, as the temper-graphite of Ledebur.

The temper-graphite condition of carbon was, in his opinion, most desirable in castings. It was only formed from the carbide after the metal had become solid. It existed in the finest possible state of division, and not in plates of large dimensions.

If they took, say, No. 1 hæmatite iron in the fluid state, and cast a portion of it into a sand mould and a second portion into water or a chill, the first would be open and grey, the second would be quite white and brittle; but if the white chilled iron was to be heated up again and maintained at a red-heat for a short time, and was cooled slowly from that temperature, the whole or nearly the whole of the graphite would separate out in the form of temper-graphite, and the casting would then have ideal physical properties and be much stronger than the metal cast in sand, yet ordinary analysis would not show any difference in the ultimate composition.

He (Mr. Stead) had come across many castings in which the graphite existed both in plates and as temper-graphite, the former crystallising out coincidentally with the solidification of the metal, the latter after solidification.

On dissolving a small piece of such metal in nitric acid and then treating the residue with hydrofluoric acid, it was easy to see that there was a black powder present, in addition to the comparatively massive plates of graphite. The black powder was the temper-graphite.

They had no method at present excepting such a qualitative one as that just described for determining the relative quantities of carbon in these two forms. There was a field open in this direction for research and advance.

The difference in the properties of the semi-steels Nos. 479 and 583, referred to by Mr. Summers, certainly appeared to be due to difference in the carbon condition. He had occasionally met with the same kind of differences in semi-steels, but found it difficult to explain why they should occur. Here again was a second field open for investigation.

Mr. Summers was quite correct in stating that temper-graphite appeared to be more uniformly distributed through the metal

than ordinary graphite, but he (Mr. Stead) did not consider the author justified in considering it to be carbon in a transition state toward graphite. He had separated a large quantity from an American black-heart casting, in which practically the whole of the carbon existed as temper-graphite, and he had found it to be a good conductor of electricity, and gave the characteristic streak of black-lead; he therefore considered it to be true graphite, and not any transition form. White iron on annealing increased in bulk to an extent corresponding to the carbide carbon converted into graphite temper-carbon.

It was highly probable that Mr. Summers was right in his opinion that the difference in permeability, in the two samples referred to, was caused by the carbon being in the isolated graphite plate form in the poor sample, and in the temper-graphite perfectly distributed form in the metal which gave the best results.

The remark of Mr. Summers regarding the so-called antiquated, incorrect, and prevalent idea that more scrap could be used in a cupola if it was accompanied with ferro-silicon, he believed was opposed to practice and experience. On re-reading the paper, however, it would lead one to believe that the scrap referred to was burnt cast iron or steel, and not ordinary broken-up cast metal.

His experience went to show that old metal scrap covered with rust, on being melted alone, gave a hard casting, sometimes quite white; but the peculiarity about such metal was, not that the carbon was too low, but that the silicon had been impoverished, and he had found, and believed it was common knowledge, that an addition of ferro-silicon to such metal restored the qualities of softness and greyness. Large quantities of silicon-iron were sold in this country to enable the founder to use up old scrap with advantage.

Years ago Mr. Charles Wood and the writer (Mr. Stead) melted together white Cleveland iron and glazed iron containing 5 per cent. of silicon, and obtained good castings, soft and grey, and actually stronger than those made from the same brand of Foundry 4 iron melted alone.

If they were to conclude that the scrap containing little carbon, referred to by Mr. Summers, was steel, it was easy to

agree with the statement "that if scrap is introduced into a mixture, the amount that can be safely added depends upon its carbon contents and the carbon contents of the other ingredients of the mixture. Consequently a scrap impoverished in carbon can only be added in such amounts as not to lower the carbon content of the mixture beyond a certain minimum."

According to Table III., increasing the silicon did not diminish the graphite; the total and combined carbon were reduced, and as the combined carbon was what made the metal hard, its removal must be followed by softening of the metal. It would appear, then, that the dangerous minimum of carbon, referred to by the author, was not reached when it was reduced from 3.74 per cent. to 3.4 or 3.3 per cent.

As average old scrap iron contained about 3.3 per cent. carbon, it would be clear that by using such scrap there was no danger of reaching, by its use, the condition feared of a too low carbon content.

Referring now to the question as to the effect of phosphorus on the carbon condition in pig iron, he had made trials years ago to enable him to answer it, by running metal from a ladle into two moulds, one of which contained a stick of phosphorus. The irons when cold proved that the metal to which phosphorus had been added contained a slightly larger proportion of combined carbon. On the other hand, comparing the average analyses of Cleveland iron, containing $1\frac{1}{2}$ per cent. phosphorus, with haematite iron, containing 0.04 per cent., there was no difference in the combined carbon when the amount of silicon in each was about the same.

He was making systematic research to determine the influence of varying proportions of phosphorus on the carbon condition and quantity in pig iron, and would publish the results when the research was completed.

Many years ago he had subjected to hydraulic pressure a slowly cooling and almost solidified mass of Cleveland grey iron, by which means he had squeezed out the portions last fluid. These were high in phosphorus, and the following analyses were most instructive as bearing directly on the relations which exist in combinations of carbon and phosphorus with iron:—

| | Original Metal. | Metal Squeezed Out. |
|--------------------------------|--------------------|------------------------|
| | Per Cent. | Per Cent. |
| Iron (by difference) | 93.365 | 90.122 |
| Combined carbon | 0.550 | 1.750 |
| Graphite | 2.450 | ... |
| Manganese | 0.355 | 0.288 |
| Silicon | 1.630 | 0.790 |
| Sulphur | 0.120 | 0.060 |
| Phosphorus | 1.530 | 6.840 |
| Titanium | 0.240 | 0.150 |
| | 100.000 | 100.000 |

It was interesting here to note that in the expressed fusible metal the phosphorus amounted to nearly 7 per cent. and that the carbon was all combined. It was also remarkable that the sulphides were not squeezed out with the phosphides. Probably the sulphur had combined with the manganese and solidified at a temperature lower than the melting-point of the phosphide.

The conclusions of the author on the influence of the elements on cast iron on the permeability were worthy of note, viz. :—That phosphorus and silicon have little direct effect within certain limits. That manganese and sulphur probably effect the result indirectly by their power in promoting the formation of combined carbon. That carbon condition is the chief factor in the effect of permeability and hysteresis. That in general low combined carbon is coincident with high permeability and low hysteresis.

The remarkable effect of manganese in both semi and ordinary steels, containing about 0.6 per cent. carbon, in increasing the retentivity of magnetism, was clearly demonstrated by the author ; the difference between steels containing 0.27 and 0.77 per cent. manganese approximating to a magnetic value of 10 to 14, respectively.

In discussing the reason why manganese, which was not magnetic, should have such a powerful influence, the author considered that just as carbon in the hardening combined state had an effect on the magnetic properties, it was legitimate to conclude that manganese was also in the combined form.

It must be remembered that manganese and iron, alloyed without carbon, would not make permanent magnets, and that the increase in permanent magnetism when manganese, iron, and

carbon were associated together in the proportions given by the author in hardened steel must be due to some triple combination of these elements. It was possible also that, in the presence of manganese, when the heating was constant, the carbon was more perfectly diffused, and a greater proportion of it was retained on quenching in the hardening state than it was when less manganese was present.

There might also be a difference in the allotropic condition of the two classes of steel. The questions raised by the author were most interesting, and no doubt in the course of time they would be answered to complete satisfaction.

The PRESIDENT said there was another paper on the list, and it bore the distinguished name of Tschernoff. He need hardly say that they should have been very glad to have discussed it, but the hour was very late, and Mr. Stead had promised a communication in writing in respect to it. Its title was: "The Manufacture of Steel Direct from the Ore in the Blast-furnace."

The following paper by Mr. Dimitris Tschernoff was then taken as read:—

THE MANUFACTURE OF STEEL DIRECT FROM THE ORE IN THE BLAST-FURNACE.

BY DIMITRIS TSCHERNOFF (St. PETERSBURG).

MANY attempts have been made in the past to employ gas in lieu of solid fuel in the blast-furnace, and also to work the furnace so that iron or steel may be produced direct from the ore. Up to the present time these endeavours have not had much success, and the writer, therefore, ventures to suggest a construction of blast-furnace by which these desired ends may be attained. The furnace is designed so that the operations of reduction and of melting take place at different levels, and under the influence of two separate supplies of gas. The gas for reduction of the ore is highly heated, and is led into the furnace at about the height of the carburising or cementation zone in an ordinary furnace, and thence it flows upwards, reducing the ore during its passage. Gas for melting purposes, together with the air requisite for its combustion, is admitted to the hearth of the furnace, where it melts the metal and slag which flow into a separate hearth or receptacle, while the products of combustion are removed by side-ports and a chimney.

The figures show the proposed construction of the furnace in a somewhat diagrammatic fashion, Fig. 1 being a vertical section; Fig. 2, a section on the line 2—2 of Fig. 1; Fig. 3, a part elevation and

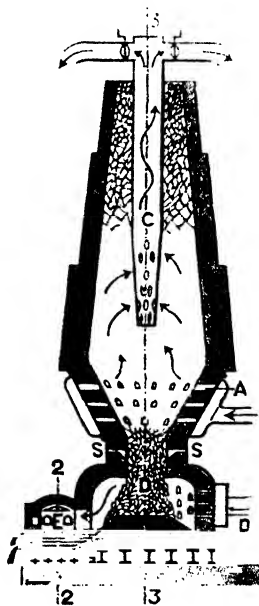


FIG. 1.

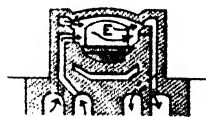


FIG. 2.

part section on the line 3—3 of Fig. 1; while Fig. 4 illustrates the construction of the upper gas ports.

Ore and flux, with which charcoal or coke may be mixed, are charged into the shaft, and are subjected to the action of gas supplied at a temperature of 1000° to 1200° C. through the ports *a* from the gas-producers N.

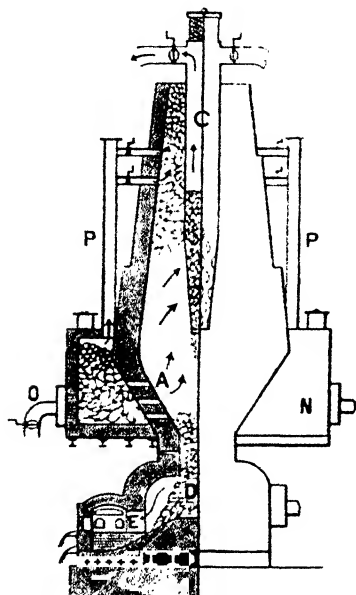


FIG. 3.

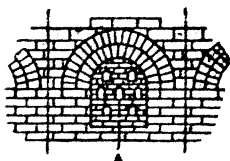


FIG. 4.

This gas flows through the charge, and is withdrawn through openings in the central tube C. Reduced ore with the flux falls into the hearth D, where it is melted by air and gas from the ports *d*. The flames pass around the mass into the hearth or reservoir E, where the melted metal and slag collect, and thence the products of combustion are drawn off by a chimney. Slag is tapped off by an upper taphole, and the remaining metal can then be treated on this hearth exactly as is done in an ordinary open-hearth furnace, after which it is tapped and cast. This hearth is shown as quite close to the shaft of the furnace, but obviously it could be placed at some distance and connected to the melting chamber by a covered conduit. The producers N may similarly be placed at a distance. Sight holes, *s*, are provided near the base of the stack, and can be used for stirring the charge or for the intro-

duction of specially fusible fluxes such as fluor spar, if the conduct of the operation calls for such additions.

The nature of the final product, cast iron, wrought iron, or steel, may be controlled by adding carbonaceous material to the charge, and by regulating the amount and the reducing power of the gas at the upper and lower gas inlets. To obtain cast iron, about 5

per cent. of charcoal or coke should be added to the ore, and the temperature and volume of the injected gases must be increased. To produce wrought iron no addition of carbon to the charge is made, and the temperature of the reducing gas must be lowered, but the temperature in the melting-hearth must be raised. In this manner the reduction and carburisation are retarded, and the rate of melting, and therefore of the descent of the charge, are increased. For obtaining more or less mild steel, intermediate measures are taken.

The gas-producers N, as will be seen in Fig. 3, are arranged on the walls of the furnace between the standards supporting the brickwork of the shaft and the boshes of the furnace. Preferably arches are turned in the main brickwork so as to allow of ready repair of the masonry where the producers are placed, as shown in Fig. 4. Another special feature is the method of working the producers. They are charged with fuel from hoppers on their tops as usual, but pipes, P, are provided to lead moisture, tarry matters, and other products of distillation of the coal to the upper part of the blast-furnace. Air is blown in near the base of the producers at O, and the carbonic oxide generated is forced into the furnace through the ports *a*. These hot gases heat the descending ore and also reduce it, so that when they enter the central pipe C, they have a temperature of at least 800° C. Accordingly, they may be regenerated by filling this pipe with fuel, of which the surplus together with the ashes subsequently mixes with the charge. The regenerated gas, enriched if necessary, is utilised for melting purposes in the hearth, or liquid fuel may be used in its place.

CORRESPONDENCE.

Mr. J. E. STEAD, Member of Council, pointed out that many years ago he had devised a very similar scheme to that of Mr. Tschernoff. It was shortly after the introduction of the Thomas and Gilchrist process for the manufacture of steel, and his ambition was at that time to make steel free from phosphorus in the blast-furnace from phosphoric ores.

The preliminary experiments were made in large crucibles. The crucibles were first brasqued with charcoal, and in these internal crucibles of basic material were placed. Into the latter Cleveland calcined ironstone was placed mixed with a sufficient quantity of lime to form a basic slag with the acids of the ore. Open passages communicated through the upper part of the lime crucibles to the charcoal lining outside. Basic material covers were placed on the internal crucibles, and these were covered with charcoal and the latter covered with a fireclay lid. The following sketch will make the arrangement clearly understood :—

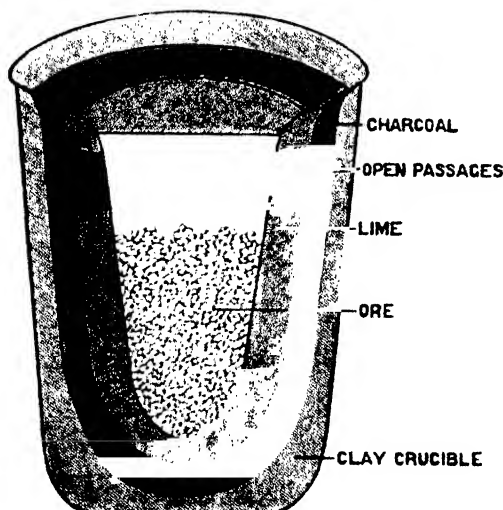


FIG. 5.

No charcoal was mixed with the ore.

The crucibles were placed in a crucible furnace, and were heated up steadily and slowly to a white heat. They were then removed. In every case a button of steel containing not more than 0·1 per cent. phosphorus was obtained, although, if the ore had been melted in the ordinary way, it would have been 1·5 per cent.

The phosphoric acid in presence of excess of lime could not be reduced by carbonic oxide gas. The carbonic oxide necessary for the reduction was of course produced from the charcoal and oxygen of the air enclosed in the crucible and the oxygen in the ore. When the temperature was raised very slowly, the carbon exceeded 1 per cent. in the steel; when quickly raised, it was about 1 per cent.

There was no carbon in the ore, and that found in the steel must have been derived from the carbonic oxide, which, as had been shown by Sir Lowthian Bell, deposited carbon when passed over oxides of iron at comparatively low temperatures.

More carbon would be deposited when the reduction was prolonged than when rapidly effected, and in this way might be explained the variation in the carbon found in the melted steels.

In the endeavour to design a furnace by which to conduct the manufacture of the iron on a commercial scale, very serious practical difficulties presented themselves, and as these applied equally to the design of Mr. Tschernoff, they were given in detail here.

1. The carbonic oxide gas produced in burning coke or coal in a producer was accompanied with sulphurous gases, and the sulphur would be retained to a very large extent by the oxides of iron in the furnace. Therefore charcoal would have to be employed, which would be too expensive.

2. The temperature would have to be so low as to avoid any sintering of the ore and flux in the shaft of the furnace, for if it rose to sintering-point it would *set* in a solid scaffold, and the running of the furnace would be terminated, for there would be no means of opening it again.

3. The reduction of the ore would be at least as slow as in the ordinary blast-furnace, and there would necessarily be much carbon deposited in the ore, and this would probably be sufficient to more or less completely carburise the iron, so that

when melted (unless the melting was done in an oxidising atmosphere) there would be white pig iron produced instead of steel, which would contain a large proportion of sulphur. Such iron would be useless for steel-making.

4. If the temperature was so low as to prevent sintering, the flux would be useless in the furnace, and would only come into action when it entered the melting hearth in company with the spongy iron impregnated with carbon.

5. If the iron was in spongy form when it entered the chamber near to the open hearth, and came in contact with the oxidised products of the burning gas, the oxidation of this iron would be enormous. According to Mr. Holley, the spongy iron from Blair's process had to be compressed before it was heated preparatory to charging it into the open-hearth furnace, otherwise the oxidation of the iron was great. It was also necessary to plunge the heated compressed spongy iron into an initial bath of metal to avoid further oxidation. Now, in either his own plan or that described by the author, it would be impossible to compress the reduced iron or rapidly drop it into an initial bath.

6. The apparatus designed was necessarily too complicated, and parts of it out of reach and control.

He was much afraid that the objections to his (Mr. Stead's) scheme applied with equal force to Mr. Tschernoff's. The difficulties appeared to be insurmountable.

The blast-furnace producing liquid iron, which in less than an hour could be converted into Bessemer steel ingots, and in a few hours be turned into excellent steel in the open-hearth furnace, was hard to beat, and he greatly feared that any more complicated and more difficultly controllable process would have little chance of existence against such a formidable rival.

The following papers were taken as read :—

THE USE OF HOT-BLAST IN THE
BESSEMER PROCESS.*

By PROFESSOR J. WIBORGH (SCHOOL OF MINES, STOCKHOLM).

ALTHOUGH the Bessemer process has been in general use for more than thirty years, no serious attempts have, so far as my knowledge goes, been made to use hot-blast for this process. Long experience has taught us the great advantages to be gained in the manufacture of pig iron, and in other metallurgical processes, by using heated instead of cold air for the combustion. Why should not the same be the case in the Bessemer process? This process is also one of combustion, where silicon, manganese, phosphorus, and so forth combine with the oxygen of the air; and is it not likely that, all other conditions being equal, this combination or combustion shall take place with greater facility if the air has been previously heated? Observations tend to show that the Bessemer process, treating the same kind of pig iron, runs off with a somewhat warmer blow in hot summer days than in the cold winter. This is no doubt partly due to the fact that the converter and ladle in the former case, as a rule, are warmer, and the radiation of heat less than in the latter; but it is probable that the temperature of the blast here already exercises an appreciable influence, although the difference of temperature can hardly be estimated to exceed 50° C. It is very likely, therefore, that were the temperature of the blast to be raised to some 400° or 500° C., a considerably warmer blow would be the result, a pig iron poorer in silicon could be used, the tuyeres would not be so easily clogged up, and the loss would be less. More especially in the case of small converters the hot-blast would no doubt prove beneficial, as also in general when charcoal pig is used and in the basic Bessemer process. In the latter case it is not improbable that by the aid of the hot blast, pig

* This paper was received from the author on August 26, 1898, too late to be included in the programme of the Stockholm Meeting.

iron of a comparatively low percentage of phosphorus could be used, and still a sufficiently high temperature be reached at the end of the process.

It is specially for small converters and for the basic Bessemer process that the hot-blast is advantageous.

In the experiments made at Zeltweg, in Styria, in 1873, the hot-blast was thought to destroy the bottom of the converter more rapidly. This disadvantage ought not to be met with in the basic process; on the contrary, the more the percentage of silicon in the pig iron can be reduced by the use of hot-blast, the longer the tuyeres and the bottom ought to last.

As regards the heating of the Bessemer blast, it would appear at first sight as if very large and expensive apparatus would be required for the purpose, but on giving the matter closer consideration it will be found that a hot-blast stove of the same type as the regenerative stoves employed for blast-furnaces will assume very modest dimensions when used in combination with a Bessemer converter for the following reasons:—

1. In the Bessemer process, it is true, the required volume of blast per second is great, but inasmuch as the process has but a short duration, the total volume of blast which has to pass through the stove is small as compared with that passing through a regenerative hot-blast stove for a blast-furnace in the time between the reversal of the valves. For instance, if eight tons of pig iron are to be decarburised in a Bessemer converter with a hot-blast of 400° C. temperature, the heating apparatus need only furnish 300,000 heat-units for heating the blast; but if the blast of an ordinary coke blast-furnace is to be heated to the same temperature in a regenerative heating stove, the valves being reversed once every hour, the stove must give off 1,500,000 heat-units, and accordingly have five times the size required for that for the converter.

2. A uniform temperature of the blast is generally to be regarded as a requisite condition for a satisfactory working of the blast-furnace; but when a regenerative heating apparatus is used, it is self-evident that the temperature must fall by degrees during the passage of the blast through the heated stove, since the latter cools off in the meantime, and it is only by giving gigantic

dimensions to such stove that it has been possible to reduce the fall of temperature sufficiently to avoid any detrimental influence from this cause.

In the Bessemer process the conditions are quite different. Here the blast must penetrate the bath of hot metal, and in so doing it will always cause a cooling action to take place, which, however, in the course of the process must be more than counter-balanced by the combustion of silicon and manganese contained in the pig iron. In the beginning of the process, and when the temperature of the pig iron is low, this cooling is easily apt to cause great inconvenience by thickening the metal of the bath, thus impeding the passage of the blast through it, and hence causing stopping and slower oxidisation. By the use of hot-blast such cooling is diminished, and it should, therefore, prove of great advantage, especially at the beginning of the process, when the charge has its lowest temperature, whereas, in the same measure as the temperature subsequently rises owing to the oxidisation, the temperature of the blast might be lowered considerably without prejudicing the blow.

For reasons easily understood, this circumstance tends to prove that a stove for heating the Bessemer blast would require but comparatively small dimensions.

3. The Bessemer process requires a high pressure of the blast—from one to two atmospheres—but, as a consequence, the air passing through the heating stove (and conduits) will have a considerably reduced volume, and that tends also to reduce the dimensions of the apparatus.

Approximate Calculation of the Size of a Bessemer Blast-Stove.—Assume that the converter holds a ton of pig iron, and that for each ton are required 300 cubic metres of air of 0° C. and 760 millimetres, and that this air, after having passed through the stove in the beginning of the blow, has a temperature of 500° C., but at the conclusion is of 400° C. only, the fall of temperature thus being 100° C., the average temperature of the blast accordingly is 450° C. Assume, further, that the duration of the blow is ten minutes, and that the pressure of the blast is 1000 millimetres above that of the atmosphere.

The Volume of the Regenerator.—As one cubic metre of air

weighs 1.29 kilogramme, and its specific heat is 0.24, the quantity of heat required for heating the air will be—

$$a \times 300 \times 1.29 \times 0.24 \times 450 = 41,800 \times a \text{ heat units.}$$

This quantity of heat must be given off by the heating stove. One cubic metre of brick weighs 2000 kilogrammes, and its specific heat is 0.25. Assuming that the air passages of the regenerator occupy half its volume, each cubic metre of the regenerator will contain 1000 kilogrammes of brick only, and if its total volume is x cubic metres, the weight of the brick will be $1000 x$ kilogrammes. For each degree that it cools off, this mass of brick gives off $x \times 1000 \times 25$ heat units. As the temperature of the blast during the blowing is assumed to fall 100°C. , and this fall in temperature is the result of a corresponding cooling of the regenerator, the temperature of the latter also must fall by 100°C. , and hence the following equation is obtained :—

$$\begin{aligned} x \times 1000 \times 0.25 \times 100 &= 41,800 \times a \\ x &= 1.7 \times a. \end{aligned}$$

Note.—For an 8-ton converter the volume of the regenerator will be 13.5 cubic metres.

| | | | | | | | | |
|-----------------------|---|---|---|---|---|---|------|---|
| For a 6-ton converter | . | . | . | . | . | . | 10.2 | „ |
| For a 5-ton converter | . | . | . | . | . | . | 8.5 | „ |

The Diameter of the Regenerator.—Denoting by V_0 the required volume of air at 0°C. and 760 mm., and by V^1 the same volume heated to 450°C. and having a pressure of 1000 mm. above that of the atmosphere, these volumes will bear the following relation to each other :—

$$V_0 = \frac{V^1}{(1 + 0.00367 \times 450)} \times \frac{(1000 + 760)}{760}$$

and since $V_0 = 300 a$, as assumed above, we shall have—

$$V_1 = 300 \times a \frac{(1 + 0.00367 \times 450)}{1.760} \times \frac{760}{760} = 343.3 \times a \text{ cubic metres.}$$

When the duration of the blow is ten minutes, the volume of air per second will be

$$\frac{343.3}{10 \times 60} a = 0.57 \times a \text{ cubic metres.}$$

If the regenerator is of circular section with a diameter D , its sectional area will be $\frac{\pi D^2}{4}$, and the sum of the area of the air-

passages, which is to be one-half of that of the regenerator, will be $\frac{\pi D^2}{8}$. Assuming the velocity of the heated air in the regenerator to be 4 metres a second, which cannot be considered excessive, the volume of air passing through the stove per second will be $\frac{\pi D^2}{2}$ cubic metres. This volume, however, has been previously calculated to be $0.57 a$ cubic metres, and consequently the diameter of the regenerator is obtained from the equation :

$$\frac{\pi D^2}{2} = 0.57 a,$$

or

$$D = \sqrt{0.363 a}.$$

Note.—For an 8-ton converter the diameter of the regenerator is equal to 1.70 metres.

For a 6-ton converter 1.45 „

For a 5-ton converter 1.35 „

The Height of the Regenerator.—If h denotes the height, and D the diameter of the regenerator, its volume is $\frac{\pi D^2 h}{4}$, and since diameter and volume are previously determined to be $\sqrt{0.363 a}$ and $1.7 a$ respectively, we obtain :

$$\frac{\pi 0.363 \times a}{4} \times h = 1.7 a$$

and hence $h = 6$ metres.

The height of the regenerator thus is always the same, 6 metres, and its diameter only varies with the size of the converter. It is willingly admitted that the above calculation cannot be perfectly accurate, since it is based only on the weight of the bricks of the regenerator, and no attention has been paid to its surface; at all events, however, it affords clear evidence of the fact that a stove for heating the Bessemer blast does not assume any large dimensions.

Area of Tuyeres of the Converter, and Power required when Hot-Blast is used.—The refining operation consists in an oxidation of silicon, manganese, carbon, &c., and for this purpose a corresponding quantity of oxygen is required, this quantity consequently varying with the percentage of these elements in the pig iron. Experience has proved, however, that this required quantity of oxygen on an average and per ton pig iron, is fully supplied by

300 cubic metres of air of 0° C. and 760 mm. If hot-blast of the temperature t° is to be used, and the blowing operation be completed in the same time as with cold-blast, the area of tuyeres must be made $(1 + \alpha t)$ times greater, or else the duration of the blow must be prolonged. In both cases a correspondingly increased consumption of power is required in order to force the blast through the charge. It thus appears as if the hot-blast would be unfavourable in this respect. In reality, however, the matter will no doubt assume another aspect. By analysis of gases escaping from the converter in the Bessemer process, according to the analyses made by A. Tamm and G. J. Snelus, it has been ascertained that in the beginning of the blow, and sometimes during the whole operation, free oxygen passes through the charge. It is more especially when the temperature is low, or the depth of the bath is small, that not all of the oxygen is consumed, and the consumption of blast becomes greater than it should be. It is quite evident, however, that hot-blast favours the combustion, and consequently the absorption of oxygen, and as a result the weight of blast required in practice will be less than is now needed with cold-blast, and moreover that the depth of the bath can be reduced. Both of these factors serve to counteract the increase in the consumption of power which would otherwise result from the greater volume of the hot-blast.

The heating apparatus ought to be built up in such a way that the temperature of the blast may be varied at will.

The heat which can be transmitted to the charge by means of such a heating stove is by no means insignificant. According to the preceding calculation, the blast when at a temperature of 450° C. carries with it 41,800 heat-units for each ton of pig iron to be refined. Assuming the specific heat of molten pig iron to be 0.3, this quantity of heat should be able to raise the temperature of the charge by

$$41,800 = 1000 \times 0.3 x^{\circ}.$$

or

$$x = 140^{\circ} \text{ C.}$$

Professor Ledebur has calculated that 1 per cent. of silicon in the pig iron will raise the temperature of the charge by 300° C.,

and 1 per cent. of phosphorus by 183° , and it appears, therefore, as though by means of a hot-blast of 450° C. temperature it would be possible to produce an effect corresponding approximately to the presence of $\frac{1}{2}$ per cent. of silicon or $\frac{3}{4}$ per cent. of phosphorus in the iron. Adding to the above, that the temperature of the blast can be regulated at will, it appears that a stove for heating the Bessemer blast would form an excellent regulator for obtaining a steel of the proper degree of heat without the need of adding foreign substances to the metal.

CONSIDERATIONS ON THE SOLUTION THEORY OF IRON AND STEEL.

BY BARON JÜPTNER VON JONSTORFF, DONAWITZ.

THE author has, in two former communications, sought to apply the laws of solution to iron and steel, and has in a third short treatise * extended this research to other metallic alloys. The present work is intended to bring still further consideration to this research.

I.—*General Considerations as to the Solution Theory, Retaining the Former Symbols.*

M = The molecular weight of the dissolved body.

m = The amount of the dissolved body in 100 parts by weight of the solvent.

t = The depression of the fusion-point in degrees C.

E = The molecular fusion-point depression of the solvent.

T_o = The fusion-point of the solvent in absolute temperature.

w = latent heat of fusion of the solvent.

We have in general (see Fig. 1)—

$$M = \frac{m}{t} E,$$

$$m = f(t),$$

$$\tan \alpha = \frac{dm}{dt},$$

$$\tan \beta = \frac{m}{t},$$

Then M can only be constant when $\frac{m}{t}$ is constant, and $m = f(t)$ forms a straight line which passes through the fusion-point S of one of the constituents of the solution (the solvent).

In every other case M varies, and M increases with increasing m when $\tan \beta = \frac{m}{t} < \tan \alpha = \frac{dm}{dt}$, and M falls with increasing m when $\tan \beta = \frac{m}{t} > \tan \alpha = \frac{dm}{dt}$.

* *Stahl und Eisen*, 1899, No. 1.

The latter case, however, is only found in a single group of alloys—viz., in those in which the constituents form an isomorphic mixture, as sometimes occurs.

If a part of the fusion curve is a straight line, but one which does not pass through the fusion-point of one of the components, its equation is (symbolising by m_w and t_w the co-ordinates of the turning-point at which the curved line passes into the straight one)—

$$\begin{aligned} m &= (t - t_w) \tan \alpha + m_w, \\ &= (t - t_w) \frac{dm}{dt} + m_w, \end{aligned}$$

and

$$\begin{aligned} \frac{m}{t} &= \tan \beta = \frac{t - t_w}{t} \cdot \frac{dm}{dt} + \frac{m_w}{t}, \\ &= \frac{m_w}{t} + \frac{dm}{dt} - \frac{t_w}{t} \cdot \frac{dm}{dt}, \\ &= \frac{m_w}{t} + \tan \alpha - \frac{t_w}{t} \cdot \tan \alpha, \\ &= \tan \alpha \left(1 - \frac{t_w}{t} \right) + \frac{m_w}{t}, \end{aligned}$$

an equation which one can, for example, employ in the calculation of the molecular weight of the dissolved carbon from the second straight-lined axis of the solidification curve of the iron in molten iron-carbon alloys.

We have for this, i.e. for $C' = 2.4$ per cent. to $C = 4.3$ per cent., the equation—

$$T_c = 1469 - 83.3 \frac{100}{100 - C'}$$

and further,

$$\begin{aligned} m_w &= \frac{100 \cdot 2.4}{100 - 2.4} = 2.46, \\ t_w &= 335, \\ \tan \alpha &= \frac{m}{t - t_w} = \frac{4.49 - 2.46}{470 - 335} = 0.01503, \\ \frac{m}{t} &= \tan \beta = 0.01503 \left(1 - \frac{335}{t} \right) + \frac{2.46}{t}, \\ &= 0.01503 - \frac{2.58}{t}, \\ M &= \frac{m}{t} E, \\ &= \left(0.01503 - \frac{2.58}{t} \right) \cdot 3273, \\ &= 49.19 - \frac{8444.34}{t}, \end{aligned}$$

and thus we obtain for the molecular size of the dissolved carbon in the molten iron:—

| Temperature | M. | n. | Remarks. |
|------------------|-------|------|----------------------|
| 1600 to 1336° C. | 24.54 | 2.07 | } As formerly given. |
| 1320° C. | 23.84 | 2.00 | |
| 1270° C. | 24.87 | 2.07 | |
| 1250° C. | 25.07 | 2.09 | } As formerly given. |
| 1225° C. | 26.37 | 2.19 | |
| 1200° C. | 28.04 | 2.34 | |
| 1175° C. | 29.32 | 2.44 | |
| 1150° C. | 30.43 | 2.53 | |
| 1130° C. | 31.22 | 2.60 | |

From this it is seen that the alteration of the size of the molecule of the dissolved carbon is greatest between 1200° and 1225° C., but decreases in both directions from this temperature; so that the carbon molecule between 1600° and 1270° C., and probably also a little below 1130° C., is constant.

If a part of the fusion curve run perpendicular to the temperature axis, and $t = \text{constant}$ and $\tan a = \infty$, then

$$\frac{m}{t} = \tan \beta = \frac{m}{t_{\infty}},$$

that is to say, that the increase of the molecular weight M of the dissolved body must be proportional to the increase which it simultaneously receives. This can only take place, however, when t , m , and M are all constant, that is to say, in the case of the eutectic alloy, and where the fusion curve reaches a maximum, and where it refers to a single constituent (whether this be an original one or a combination of an original one is a matter of indifference). In the latter case we have only to deal with *one* point in the fusion curve, and this represents the fusion-point of the constituent under consideration.

The other case, $\tan a = 0$, and $\tan \beta = \frac{m_{\infty}}{t}$, is physically impossible.

In alloys which represent *isomorphous mixtures of their constituents*, and in which also the fusion-point curve rises opposite to one of the constituents (Fig. 2), t is negative, so $\tan a$ and $\tan \beta$ will be also negative; on the other hand, E is also negative in this case, so that

$$M = \frac{m}{t} E$$

has a positive value. In reference to the increase and decrease of M , this expression has the same value as before, *i.e.* with increasing m , M increases if the curve is curved upwards, M decreases if the curve is curved downwards, and M remains constant if the curve forms a straight line passing through S .

If we consider in an isomorphous mixture a point P of the fusion curve (Fig. 3) in relation to the components of the solution, we find

$$t - t_1 = S_1 - S = \theta = \text{a constant,}$$

and—

$$a = a_1.$$

If we further express by p and p_1 the percentage composition of both components, then

$$m = \frac{100p}{100 - p}$$

$$m_1 = \frac{100p_1}{100 - p_1}$$

and because $p_1 = 100 - p$

$$m_1 = \frac{100(100 - p)}{100 - (100 - p)} = \frac{10000 - 100p}{p} = \frac{10000}{p} - 100$$

and from this follows—

$$\tan a = \tan a_1 = \frac{dm}{dt} = \frac{dm_1}{dt_1},$$

$$\tan \beta = \frac{m}{t} = \frac{100p}{(100 - p)t},$$

$$\tan \beta_1 = \frac{m_1}{t_1} = \frac{10000 - 100p}{p \cdot t_1} = \frac{10000 - 100p}{p(\theta - t)} = \frac{100(100 - p)}{p(\theta - t)}$$

Whilst the size of the molecule of the one body increases, that of the other decreases, and *vice versa*. This shows that both constituents of a solution influence each other, and that the increase of the molecule of one constituent corresponds with a diminution of the molecule of the other constituent of the solution; so that a certain tendency exists to bring about a mean size of molecule. This phenomenon may perhaps furnish a means of finding a relation between the molecular weight and the value of E ; but, on the other hand, this simultaneous variability of the size of the molecule of the two components of the solution shows why the laws of solution only apply sufficiently nearly in the case of relatively dilute solutions.

If we express the relative number of the molecules present in an alloy by μ and μ_1 , then

$$\mu = \frac{p}{M} = \frac{p}{\tan \beta \cdot E} = \frac{p}{100 - p} \cdot \frac{p}{t} \cdot E,$$

$$\mu_1 = \frac{p_1}{M_1} = \frac{100 - p}{\tan \beta_1 \cdot E_1} = \frac{100 - p}{p(\theta - t)} \cdot \frac{p_1}{t_1} \cdot E_1,$$

and the total number of molecules present

$$\mu + \mu_1 = \frac{(100 - p)t}{100E} + \frac{p(\theta - t)}{100E_1} = \frac{1}{100} \left[\frac{p_1 t}{E} + \frac{p t_1}{E_1} \right]$$

that is to say, that the sum of $\mu + \mu_1$ is constant when $\frac{p_1 t}{E}$ and $\frac{p t_1}{E_1}$ are constant, or the sum of $\frac{p_1 t}{E} + \frac{p t_1}{E_1}$ is constant.

If now we calculate this value for two such alloys (which give isomorphous mixture) we get—

A.—For Gold-Silver Alloys.

| Gold, p . | Silver, p_1 . | t . | t_1 . | E . | $\frac{p_1 t}{E}$ | Difference. |
|----------------|--------------------|-------|---------|--------|-----------------------------------|------------------------------|
| 0 | 100 | 0 | 121 | 1217.7 | $\frac{0 \times 100}{1217.7} = 0$ | 1.38 0.64 0.15 0.47 |
| 20 | 80 | 21 | 100 | .. | 1.38 | |
| 40 | 60 | 41 | 80 | .. | 2.02 | |
| 60 | 40 | 66 | 55 | .. | 2.17 | |
| 80 | 20 | 91 | 30 | .. | 1.70 | 1.70 |
| 100 | 0 | 121 | 0 | .. | $\frac{0 \times 121}{1217.7} = 0$ | |

B.—For Gold-Platinum Alloys.

| Gold, p . | Platinum, p_1 . | t . | t_1 . | E . | $\frac{p_1 t}{E}$ | Difference. |
|----------------|----------------------|-------|---------|--------|------------------------------|-------------|
| 0 | 100 | 0 | -700 | 3055.4 | $0 \times 100 = 0$ 3055.4 | 1.39 |
| 5 | 95 | 45 | -655 | " | 1.39 | 1.11 |
| 10 | 90 | 85 | -615 | " | 2.50 | 0.97 |
| 15 | 85 | 125 | -575 | " | 3.47 | 0.85 |
| 20 | 80 | 165 | -535 | " | 4.32 | 0.71 |
| 25 | 75 | 205 | -495 | " | 5.03 | 0.46 |
| 30 | 70 | 240 | -460 | " | 5.49 | 0.46 |
| 35 | 65 | 280 | -420 | " | 5.95 | 0.23 |
| 40 | 60 | 315 | -385 | " | 6.18 | 0.21 |
| 45 | 55 | 355 | -345 | " | 6.29 | 0.01 |
| 50 | 50 | 390 | -310 | " | 6.38 | 0.07 |
| 55 | 45 | 425 | -275 | " | 6.31 | 0.36 |
| 60 | 40 | 455 | -245 | " | 5.95 | 0.34 |
| 65 | 35 | 490 | -210 | " | 5.61 | 0.46 |
| 70 | 30 | 520 | -180 | " | 5.15 | 0.61 |
| 75 | 25 | 555 | -145 | " | 4.54 | 0.70 |
| 80 | 20 | 585 | -115 | " | 3.84 | 0.82 |
| 85 | 15 | 615 | -85 | " | 3.02 | 0.91 |
| 90 | 10 | 645 | -55 | " | 2.11 | 1.01 |
| 95 | 5 | 675 | -25 | " | 1.10 | 1.10 |
| 100 | 0 | 700 | -0 | " | $700 \times 0 = 0$ 3055.4 | |

Unfortunately, the latent heat of fusion of the second component is in the case of both alloys unknown, and hence also the value of E , so that we are not able to calculate the value of $\frac{p_1 t_1}{E_1}$. However, it fortunately happens that in the one alloy the fusion-point rises with increasing gold percentage, whilst in the other it sinks.

Now we see that in both cases with intermediate percentage, *i.e.* from about 40 to 60 per cent., both expressions $\frac{p_1 t_1}{E_1}$ and $\frac{p_1 t}{E_1}$ are nearly constant, so that within this limit the number of molecules present must also be constant, and we are justified in drawing the conclusion that *the size of the molecules of both components, in the case of intermediate percentages in such alloys which form isomorphous mixtures, remains unaltered.*

This is by no means unimportant in the case of iron alloys, since the alloys of (carbonless) iron with manganese and nickel probably form isomorphous mixtures, or at least their fusion-point curve will approach very near thereto.

It remains now to investigate the special case in which the fusion-point curve of an isomorphous mixture is a straight line, which joins the fusion-point of both components (Fig. 4).

In this case not only are M and M_1 constant, but also—

$$\frac{m}{t} = \frac{m_1}{t_1},$$

$$\tan \alpha = \tan \beta = \tan \alpha_1 = \tan \beta_1$$

and consequently—

$$\frac{M}{E} = \frac{M_1}{E_1}$$

or—

$$M \cdot E_1 = M_1 E.$$

If this case does not as a matter of fact occur in practice, yet some alloys (such as gold-silver and gold-platinum) show a near approach thereto, and we can in these cases, at least, assume that

$$\frac{M}{M_1} = \frac{E}{E_1},$$

i.e. in the case of alloys whose components give isomorphous mixtures, the molecular weights of both components stand nearly in an inverse ratio to their molecular fusion-point depressions, a fact which is more especially true for the alloys of intermediate percentages, in which also, as we have just seen, the molecular weight remains nearly constant.

II.—Considerations as to the Fusion-point Curve of pure Iron Carbon Alloys.

If one considers closely fusion-point curves, such, for example, as those given by Professor Roberts-Austen * for iron-carbon alloys, it will be seen that the fusion-point curves of the eutectic alloys do not ever quite extend to 100 per cent. of that of one of the components of the solution. For the fusion-point curve of the solid eutectic iron-carbon alloys, this is explained by the fact that, where the carbon content is small, the metallic mass which has to be changed into pearlite is too small to bring about any marked effect in the recalescence curve.

In the solidifying-point curve of the fluid eutectic alloy the same explanation must suffice. It is true that the fusion curve

* Fourth Report of Alloys Research Committee, Table XI. (see Fig. 5).

of the fluid eutectic alloys can at present only be followed to about 1·8 per cent. carbon, but this percentage of carbon is not much greater than the carbide content of a steel with 0·1 per cent. carbon (1·5 per cent. carbide), up to which the pearlite curve can be traced, and is certainly smaller than the 0·1 per cent. carbon, corresponding to a percentage of 11·1 pearlite. A further very striking result is that the fusion curve of the eutectic iron carbon alloys runs only partly horizontally, and in the direction of the increasing amount of the constituent present in smaller quantity, but in the direction of the increasing chief constituent of the solution sinks downwards. This may perhaps be explained on the supposition that the eutectic alloys only possess a constant solidifying point when their masses predominate in the true alloy. On the other hand, this solidification may be retarded until the molecules of the dissolved body have, in consequence of the continued cooling, reached a certain size. However this may be, in any case when eutectic alloys separate, the size of the molecule is subjected to certain, if small, variations.

The curve *MO* in Fig. 5, which allotropists at present generally conceive to be the limiting curve between α -Fe and β -Fe, could from its appearance (as Dr. Alfred Stansfield has already remarked) also be taken equally well for an eutectic curve.*

It must then correspond to the decomposition of the poorly carbonaceous martensite into ferrite and more highly carbonaceous martensite, which would mean that Arnold's subcarbide is not perhaps a simple solution of carbide in iron, but more probably a loose molecular combination (about $\text{Fe}_3, \text{C}, \text{Fe}_{21}$). This suggestion must suffice.

In reference to the austenite curve, only two statements by Osmond are to hand; from 1·5 to 1·6 per cent. carbon austenite appears at 740°C. and upwards; with 1·0 per cent. carbon austenite begins at about 1000°C. to appear.

At present it will suffice if one combines the temperature-point, corresponding to 1·5 per cent. C., by a straight line (shown as a dotted line in Fig. 5), with the fusion-point of the pure iron, since this line reaches for 1 per cent. C 1020°C. , which in any case is a completely satisfactory agreement with the above "about 1000°C. "

* Fourth Report, p. 91.

Against the assertion that austenite is a solution of free carbon in iron, Osmond has, of course, objected that it is superfluous, since all phenomena may be sufficiently well explained by the assumption of different allotropic modifications of iron. But apart from the fact that the above hypothesis is the first attempt to clear up the nature of austenite, and that it agrees perfectly with the properties of austenite and the exact conditions of its appearance, we are driven to assume a solution of elementary carbon because the separation of graphite could only result from such a solution. In any case, it may be assumed that in the same iron both free carbon and carbide could be simultaneously present.

Up to a certain point this indeed appears to be the case, since, as is known, iron carbide at a temperature somewhere above 800° is partly dissociated, in which case the solution, besides undecomposed carbide, apparently also contains its ions; that is to say, that the martensite, which often appears alone, must, besides iron carbides, also contain its decomposition products (whether $C + Fe_3$, or $CFe + Fe_2$, or $CFe_2 + Fe$, or other combinations, is not known). But inversely iron alloys rich in manganese (according to Osmond) often contain, besides separated carbide, a formative element approaching very near to austenite. This "manganese-austenite" must, according to our hypothesis, besides free carbon, also contain a more or less considerable quantity of dissolved carbide. But there is nothing against the supposition of a separation in space of the carbon and carbide solution; semi-pig iron shows that similar separations really take place.

Starting thus with the at least not improbable view that austenite is a solution of free carbon in iron, we can, with the help of the curve AU shown in Fig. 5, reckon the molecular weight of this austenite carbon—

$$\begin{aligned}
 M &= \frac{m}{t} \cdot E \\
 p &= 1.5 \\
 m &= 1.52 \\
 E &= 3273 \\
 t &= 1600 - 740 = 860 \\
 M &= \frac{1.52}{860} \times 3273 = 5.784,
 \end{aligned}$$

and we find for the number of atoms in the molecule of the austenite carbon

$$n = \frac{5.784}{12} = 0.482,$$

which does not apparently speak well for the correctness of our hypothesis, but, rigidly taken, only shows that here we are not dealing with an ordinary iron carbon solution.

If, however, we base the calculation on the assumption that austenite is also a solution of iron carbide in iron, we have—

$$\begin{aligned} p &= 22.50 \\ m &= 29.03 \\ M &= \frac{29.03}{860} \times 3273 = 110.48 \\ n &= \frac{110.48 \times 4}{180} = 2.45. \end{aligned}$$

That is to say, that austenite, besides free iron and carbon, must also contain some undecomposed carbide. The above calculated mean molecular weight would correspond very nearly to—

| | |
|--|--------|
| 100 atoms ($= 100 \times 12$) | 1,200 |
| 100 molecules Fe_3 ($= 100 \times 168$) | 16,800 |
| 57 molecules Fe_3C ($= 57 \times 180$) | 10,260 |
| 257 | 28,260 |

then $\frac{28,260}{257} = 109.96$ gives almost exactly the value above obtained.

According to this, there is soluble in iron, besides much carbon, a certain amount of carbide, or besides carbide a certain amount of carbon. The first would be austenite, the latter martensite. So long as one of these solution limits is maintained, we are dealing with only one of the constituents mentioned; but should this be overstepped, the mass decomposes into two different constituents. Similar phenomena are also known with single fluid solutions.

According to the above calculations, the free carbon, as well as the free iron in austenite, appears to be present as ions, that is, in an electrically charged state. Does not this circumstance supply an explanation of the various magnetic and thermo-electric properties of iron alloys at different temperatures? Moreover, may not the free iron ions effect that condition which Osmond describes as γ -iron, and can a similar dissociation of the iron molecule at high temperatures not also take place in pure iron?

III.—*Molecular Size of the other Dissolved Bodies present in Iron.*

As we have seen, for the solid iron carbon solutions the absolute values of the molecular weights cannot be calculated, since the valid value of $E (= 3273)$ for fluid alloys of iron and carbon give for M impossibly small values.

An explanation of this can scarcely be found without the assumption of a change of state of the iron corresponding to (at least) two different forms of this element. Osmond has shown this in the discussion of my first paper on the solution theory of iron and steel, and he states that the fusion-point of the α -iron must be much higher than the ordinary known fusion-point of iron. This follows immediately from the results of calculation formerly arrived at.

According to all experiments, the difference between the supposed different allotropic conditions of iron (perhaps besides a different arrangement of the atoms in the molecule) must be sought more particularly in the different number of atoms which make up an iron molecule, and in all probability this molecular size will increase with decreasing temperature—that is to say, that in α -Fe we have a larger molecule than in the allotropic modification stable at a higher temperature.

With the change of the α -iron into another form of this element, a splitting up of the α -iron molecule must take place, and in order to bring this about a certain quantity of energy must be employed. As a matter of fact, Pionchon has found that by heating iron between 660° C. and 720° C., 5.3 calories became latent, which evidently were consumed in altering the condition of the iron.

This alteration of the molecular complexity of the iron can, however, have directly no influence upon the heat of fusion, for in our case the question is as to the fusion of α -iron, and not of any other modification of this element; but, on the other hand, an indirect influence may take place. The chief work which the latent work of fusion has to perform consists in every case in increasing the average distance of the individual molecules. This work increases (per molecule), at all events with the mass of the molecule, and is proportionate to it. On the other hand, this

work must also increase with the number of molecules present; and since in the same unit of weight of a body the mass of the molecules contained in it remains the same, yet the number of the molecules sinks if the molecular weight rises, therefore the quantity of the latent work of fusion must sink as compared with ordinary melting iron. Possibly also the latent heat of fusion of α -iron is smaller, but in no case can it be greater than the ordinary latent heat of fusion.

If one wishes to estimate the fusion-point of α -iron, one has, on the supposition of unaltered latent heat of fusion, and with the value $E = 56250$ as a basis (a value which is derived from the calculated molecular weight of the carbide, derived from the highly probable value of E. D. Campbell), a maximum value of

$$T_0 = \sqrt{\frac{20 \times 56250}{0.0198}} = \sqrt{56818181} = 7536^\circ \text{ C.}$$

But if one estimates the latent heat of fusion of the α -iron at only 10 calories, one finds

$$T_0 = \sqrt{\frac{10 \times 56250}{0.0198}} = \sqrt{2840909} = 1667^\circ \text{ C.}$$

It must not, however, be forgotten that, with the alteration of the fusion-point, on which our calculations of the relative molecular weights depend, t , and with it the expression $M = \frac{m}{t} E$, must vary; also that all these relative molecular weights can only be employed to show that the molecular weight of the iron carbide varies very considerably with the temperature, from which fact the polymeric theory experiences essential support, or to compare the molecular size of the various dissolved substances with each other at nearly the same temperatures.

Passing again to the particular object of our consideration, we come to the following conclusions:—

Every separation of a constituent from a solution is connected with the appearance of a recalescence-point. If in a carbonless alloy of iron with any other element only one single critical point in the recalescence curve is observable, this must correspond to the separation of this element, or of a combination of it, so that it is quite indifferent whether the iron in this case alters its (allotropic) condition or not. In the latter case both phenomena occur simultaneously.

Such iron alloys, which show only a single recalescence-point, are those with silicon, phosphorus, and tungsten, and we can attempt to estimate from this the molecular size of the dissolved body.

It is now pretty generally admitted that phosphorus is present in iron as Fe_3P , whilst silicon, according to Carnot and Goutal, is present both as Fe_2Si and also as FeSi . The first is the stable combination, on which account we base our calculations upon it. Tungsten, according to Carnot and Goutal, is present as Fe_3W .

As in these cases we have to deal with solid alloys, we can only estimate the relative molecular sizes. But since it is more convenient, for the comparison of the results obtained, to have the absolute molecular size before us, we will introduce the values $E = 3273$ (the ordinary value) and $E = 56250$ (see above); but we must not forget that the values so obtained are safe only in relation to one another, but not as to their absolute size.

1. Carbonless Steel with 4 per cent. Silicon.

Critical point at 703° . The formula Fe_2Si corresponds to—

| | | | | | | | | | |
|------------------------|---|---|---|---|---|---|---|---|-----------|
| Silicon | . | . | . | . | . | . | . | . | Per Cent. |
| | | | | | | | | | 4.00 |
| Fe_2 | . | . | . | . | . | . | . | . | 16.00 |
| Fe_2Si | . | . | . | . | . | . | . | . | 20.00 |

$$m = 25.00$$

$$M = \frac{m \cdot E}{1600 - 703} = \frac{25}{897} E = 0.027871 E.$$

This gives—

a. Taking $E = 3273$

$$M = 0.027871 \times 3273 = 91.222$$

Molecular weight of $\text{Fe}_2\text{Si} = 140$

$$\text{Number of atoms in molecule, } n = \frac{3 \times 91.222}{140} = 1.955$$

Or in round figures $n = 2$.

b. Taking $E = 56250$

$$M = 0.027871 \times 56250 = 1567.7$$

$$n = \frac{3 \times 1567.7}{140} = 33.9.$$

2. Low Carbon Silicon Steel.

In a steel containing C 0.08 per cent., Mn 0.11 per cent., Si 1.94 per cent., S 0.02 per cent., P 0.02 per cent., Al 0.06

per cent., and Fe 97.77 per cent., Arnold found only a single critical point at 730° C. It corresponds to—

| | Per Cent. |
|--|-----------|
| Si | 1.94 |
| Fe ₂ | 7.76 |
| Fe ₃ Si | 9.74 |
| $m = 10.82$ | |
| $M = \frac{10.82}{1600 - 730} \quad E = \frac{10.82}{870} \quad E = 0.012437 E.$ | |

And as above for—

$$\begin{aligned}
 a. \quad E &= 3273 \\
 M &= 0.012437 \times 3273 = 40.706 \\
 n &= \frac{3 \times 40.706}{140} = 0.8723 \text{ atoms.} \\
 b. \quad E &= 56250 \\
 M &= 0.012437 \times 56250 = 699.469 \\
 n &= \frac{3 \times 699.469}{140} = 14.99 \text{ atoms.}
 \end{aligned}$$

3. *Phosphorus Steel.*

In a steel with C 0.07 per cent., Mn 0.02 per cent., Si 0.03 per cent., S 0.02 per cent., P 1.36 per cent., Al 0.03 per cent., and Fe 98.47 per cent., Arnold found a single critical point at 718° C. Calculated at Fe_3P we have—

| | Per Cent. |
|--|-----------|
| P | 1.36 |
| Fe ₃ | 7.37 |
| Fe ₃ P | 8.73 |
| $m = 9.81$ | |
| $M = \frac{9.81}{1600 - 718} \quad E = \frac{9.81}{882} \quad E = 0.011122 E.$ | |

And further for—

$$\begin{aligned}
 a. \quad E &= 3273 \\
 M &= 0.011122 \times 3273 = 36.402 \\
 n &= \frac{4 \times 36.402}{199} = 0.73 \text{ atoms.} \\
 b. \quad E &= 56250 \\
 M &= 0.011122 \times 56250 = 625.213 \\
 n &= \frac{4 \times 625.213}{199} = 12.567 \text{ atoms.}
 \end{aligned}$$

4. *Tungsten Steel.*

In steel with C 0.08 per cent., Mn 0.14 per cent., Si 0.02 per cent., P 0.02 per cent., S 0.02 per cent., Al 0.02 per cent.,

W 1.41 per cent., and Fe 98.29 per cent., Arnold found only one critical point at 739° C. Calculated at Fe_3W we have—

| | Per Cent. |
|--|-----------|
| W | 1.41 |
| Fe_3 | 1.24 |
| Fe_3W | 2.65 |
| $m=2.73$ | |
| $M = \frac{2.73 E}{1600 - 739} = \frac{2.73 E}{861} = 0.003171 E.$ | |

And from this—

- a. For $E=3273$
 $M = 0.003171 \times 3273 \times 10^{38}$
 $n = \frac{4 \times 10^{38}}{352} = 0.118 \text{ atoms.}$
- b. For $E=56250$
 $M = 0.003171 \times 56250 = 178.369$
 $n = \frac{4 \times 178.369}{352} = 217 \text{ atoms.}$

The foregoing considerations show :—

1. That (only excepting ferro-silicon, with which possible results were obtained) in the calculation both of the phosphide and tungsten iron the fusion-point of ordinary iron cannot be taken into consideration, as it would yield much too low results.

2. That in the separation of Fe_3P and Fe_3W (and probably also of Fe_2Si), and indeed *simultaneously therewith*, α -iron is formed; and

3. That our assumptions made in regard to the molecular size of the iron carbide are not very far from the truth, since by employing the value of $E=56250$ possible values for M and m constantly result.

If we collate the values so obtained we have :—

| Temperature in ° C. | Molecular Weight of | | | | Number of Atoms in the Molecule | | | |
|------------------------|------------------------|-------------------------|------------------------|------------------------|---------------------------------|-------------------------|------------------------|------------------------|
| | $\text{Fe}_3\text{C.}$ | $\text{Fe}_2\text{Si.}$ | $\text{Fe}_3\text{P.}$ | $\text{Fe}_3\text{W.}$ | $\text{Fe}_3\text{C.}$ | $\text{Fe}_2\text{Si.}$ | $\text{Fe}_3\text{P.}$ | $\text{Fe}_3\text{W.}$ |
| 810 | 220.0 | ... | ... | ... | 4.89 | ... | ... | ... |
| 739 | ... | ... | ... | 178.4 | ... | ... | ... | 2.17 |
| 730 | ... | 699.5 | ... | ... | ... | 15.9 | ... | ... |
| 720 | 296.6 | ... | ... | ... | 6.85 | ... | ... | ... |
| 718 | ... | ... | 625.2 | ... | ... | ... | 12.57 | ... |
| 703 | ... | 1567.7 | ... | ... | ... | 33.9 | ... | ... |
| 690 | 611.3 | ... | ... | ... | 13.58 | ... | ... | ... |
| Normal | 180 | 140 | 199 | 352 | 4.00 | 3.0 | 4.0 | 4.0 |

or, in other words, the combinations under consideration approach the following average molecular formula :—

| Combina- tion. | Temperature in C. | | | | | | |
|---------------------------|-----------------------------|-----------------------------|---------------------------|-----------------------------|-----------------------------|------------------------------|----------------------------|
| | 810. | 739. | 730. | 720. | 718. | 703. | 690. |
| $n \text{ Fe}_3\text{C}$ | $1.22 \text{ Fe}_3\text{C}$ | ... | ... | $1.71 \text{ Fe}_3\text{C}$ | ... | ... | $3.4 \text{ Fe}_3\text{C}$ |
| $n \text{ Fe}_2\text{Si}$ | ... | ... | $5 \text{ Fe}_2\text{Si}$ | ... | ... | $11.3 \text{ Fe}_2\text{Si}$ | ... |
| $n \text{ Fe}_3\text{P}$ | ... | ... | ... | ... | $3.17 \text{ Fe}_3\text{P}$ | ... | ... |
| $n \text{ Fe}_3\text{W}$ | ... | $0.54 \text{ Fe}_3\text{W}$ | ... | ... | ... | ... | ... |

IV.—Missing Carbon in the Colorimetric Determination of Carbon.

Let us next consider the various phenomena which appear during the execution of the colorimetric determination of carbon.

If one dissolves (according to Osmond and Werth) natural and hardened steel in nitric acid of 24° B. , the following appearances present themselves:—

| Temperature | STEEL. | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|--|-----------|--------------------|------------------|--------------------|----|---|-------|-------|--|--------|--|--|-----------|-----------------|-------|---------|-----------------|------|-----|-------|-----|-------|--------------------|-------|--------------------|-------|
| | Natural. | Hardened. | | | | | | | | | | | | | | | | | | | | | | | | | |
| At ordinary temperatures. | 1. Solution of the iron is effected with disengagement of gas ; the solution is nearly colourless. | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 2. (a) There remains on the bottom of the flask a light, intensely black precipitate, which dissolves in a few minutes on standing, and almost instantly on shaking. No evolution of gas. Brown coloured solution. (b) Abundant dark brown flocks form in the solution, which by degrees change into a gelatinous light brown mass. On drying this consists of:— <table><tr><td>C</td><td>44.59</td></tr><tr><td>H₂O</td><td>22.50</td></tr><tr><td>Fe</td><td>8.05</td></tr><tr><td>O + N</td><td>24.86</td></tr><tr><td></td><td>100.00</td></tr></table> It is transparent and gelatinous when the iron is removed. | C | 44.59 | H ₂ O | 22.50 | Fe | 8.05 | O + N | 24.86 | | 100.00 | 2. (a) Similar sediment as in the natural steel. (b) There remains finally a light brown gelatinous precipitate, which dissolves with difficulty in the cold. | | | | | | | | | | | | | | | |
| C | 44.59 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| H ₂ O | 22.50 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Fe | 8.05 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| O + N | 24.86 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 100.00 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| At 80° to 100° C. | The precipitate (b) dissolves in the solution without perceptible evolution of gas, and colours it brown. The solution of (a) becomes bleached and is— <table><tr><td colspan="2">Relatively weak.</td><td colspan="2">Relatively strong.</td></tr><tr><td colspan="4">An evolution of gas occurs; the evolved gas contains carbon in the form of—</td></tr><tr><td></td><td>Per Cent.</td><td></td><td>Per Cent.</td></tr><tr><td>CO₂</td><td>0.215</td><td rowspan="3">} 0.342</td><td>CO₂</td><td>0.34</td></tr><tr><td>CNH</td><td>0.050</td><td>CNH</td><td>0.044</td></tr><tr><td>CO or hydrocarbons</td><td>0.077</td><td>CO or hydrocarbons</td><td>0.210</td></tr></table> | | Relatively weak. | | Relatively strong. | | An evolution of gas occurs; the evolved gas contains carbon in the form of— | | | | | Per Cent. | | Per Cent. | CO ₂ | 0.215 | } 0.342 | CO ₂ | 0.34 | CNH | 0.050 | CNH | 0.044 | CO or hydrocarbons | 0.077 | CO or hydrocarbons | 0.210 |
| | Relatively weak. | | Relatively strong. | | | | | | | | | | | | | | | | | | | | | | | | |
| An evolution of gas occurs; the evolved gas contains carbon in the form of— | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Per Cent. | | Per Cent. | | | | | | | | | | | | | | | | | | | | | | | | |
| CO ₂ | 0.215 | } 0.342 | CO ₂ | 0.34 | | | | | | | | | | | | | | | | | | | | | | | |
| CNH | 0.050 | | CNH | 0.044 | | | | | | | | | | | | | | | | | | | | | | | |
| CO or hydrocarbons | 0.077 | | CO or hydrocarbons | 0.210 | | | | | | | | | | | | | | | | | | | | | | | |

According to H. v. Jüptner, the solution of the substance *a* becomes decolourised, both in the cold and on warming to 80° C., almost in proportion to the square of the contained carbon.

According to the same authority, in dissolving this body in dilute nitric acid, a portion of the substance, increasing with the percentage of carbon, either escapes as gas or is changed into a colourless combination.

The solution of the flocculent matter described under *b*, H. v. Jüptner finds is not constant, but the loss experienced on long-continued standing (two days) is inconsiderable.

When the various appearances described above are considered in relation to the micrographic constituents (neglecting austenite, which is seldom present in ordinary steel samples), we arrive at the following conclusions:—

Influence of Dilute Nitric Acid on Steel.

1. Formation of a colourless solution with energetic evolution of gas. Ferrite, both in the free state and as contained in pearlite, dissolves as well as the iron matrix of martensite in hardened steel.

2. Separation of the intensely black residue *a*. This answers to the carbon contained in martensite (of dissolved carbon and of its carbon ions). Apparently the carbide is changed into a nitro-compound.

3. Separation of the flocculent brown residue *b*. Probably this is a nitro-product of the cementite, both of the free cementite and of that contained in pearlite, and perhaps also in part of that dissolved in martensite. (A similar classification has been given by Osmond in the *Transactions of the American Institute of Mining Engineers*.)

H. M. Howe has designated the difference between the real content of combined carbon and that found by the colorimetric method as missing carbon; * and has investigated the amount of this in the case of steel with 0.21 per cent. C, after hardening at various temperatures. He found:—

* "The Hardening of Steel," *Journal of the Iron and Steel Institute*, 1895, No. II.

| Quenching Temperature. | Missing Carbon. | Quenching Temperature. | Missing Carbon. |
|---------------------------|--------------------|---------------------------|--------------------|
| ° C. | Per Cent. | ° C. | Per Cent. |
| 880 | 0.092 | 600 | 0.034 |
| 836 | 0.095 | 599 | 0.047 |
| 797 | 0.102 | 575 | 0.029 |
| 761 | 0.082 | 532 | 0.005 |
| 733 | 0.095 | 512 | 0.018 |
| 714 | 0.102 | | |
| 713 | 0.093 | 340 | 0.000 |
| | | 263 | 0.000 |
| 698 | 0.096 | 20 | 0.008 |
| 652 | 0.100 | | |
| 650 | 0.084 | | |
| 633 | 0.084 | | |
| 626 | 0.084 | | |
| 620 | 0.091 | | |

These data are graphically represented in Fig. 6, and taking into consideration the possible errors of the colorimetric carbon determinations, a compensated missing carbon curve is found. At low temperatures this is almost *nil*, begins gradually rising between 340° and 400° C., and more rapidly at 550° C.; rises between 600° and 620° C. (Ar_1) suddenly very considerably, and then again remains nearly constant.

Combining the above with the relations derived from the solution theory and with Campbell's theory of polymeric carbides, we have at the lower temperature at which, according to Campbell, C_4Fe_{12} prevails, the smallest amount of missing carbon; with rising temperature, and with the formation of simpler carbides the carbon loss rises quite in accordance with the decomposition scheme formulated by Campbell.

A comparison of the size of the molecules of the iron carbide, as graphically represented in Fig. 6 with Fig. 7, is also of great interest. It must be here observed, however, that the latter curve depends upon the fusion-point curve (Fig. 5) of Roberts-Austen, and relates to steels with from 0 to 0.9 per cent. carbon. Obviously the missing carbon curve is dependent upon the percentage of carbon in the steel, and one must, in comparing the various parts of this curve, refer them not to similar temperatures, but to their position in reference to the critical points. If this be done, it is found that the molecular weight curve is wholly symmetrical with the missing carbon curve. Both curves show

in the zone Ar_1 a steep rise, but in Ar_2 an almost horizontal course. In other respects also both curves supplement each other. Fig. 6 teaches us that the carbide molecule under Ar_1 (to about 450° C.) is still increasing, whilst Fig. 7 indicates that the loss of carbon at and above Ar_3 is increasing.

T. W. Hogg, in his paper on "The Missing Carbon,"* has employed his colorimetric medium of estimation on hard steel, from which we extract the following results. The steel was hardened in cold brine. The first, with 3.1 per cent. carbon, contained only traces of temper carbon, manganese, and silicon; the last sample was ferro-manganese:—

| Carbon Percentage by Gravimetric Analysis. | Carbon Percentage by Colorimetric Estimation in the Hardened Steel. | Loss of Carbon in per Cent. on Steel. | Loss of Carbon in per Cent. of the Total True Carbon Content. |
|--|--|---|--|
| 0.10 | 0.06 | 0.04 | 40.00 |
| 0.14 | 0.10 | 0.04 | 28.57 |
| 0.21 | 0.10 | 0.10 | 47.62 |
| 0.25 | 0.13 | 0.22 | 48.00 |
| 0.30 | 0.17 | 0.13 | 43.33 |
| 0.35 | 0.17 | 0.18 | 51.43 |
| 0.39 | 0.23 | 0.16 | 41.02 |
| 0.45 | 0.25 | 0.20 | 44.44 |
| 0.50 | 0.28 | 0.22 | 44.00 |
| 0.62 | 0.41 | 0.21 | 33.87 |
| 0.70 | 0.35 | 0.35 | 50.00 |
| 0.75 | 0.32 | 0.43 | 57.33 |
| 0.84 | 0.35 | 0.49 | 58.33 |
| 0.92 | 0.41 | 0.51 | 55.43 |
| 1.00 | 0.50 | 0.50 | 50.00 |
| 1.25 | 0.74 | 0.51 | 40.80 |
| 1.50 | 1.10 | 0.40 | 26.66 |
| 1.64 | 1.33 | 0.31 | 18.90 |
| 1.70 | 1.35 | 0.35 | 20.58 |
| 2.40 | 2.10 | 0.30 | 12.50 |
| 3.20 | 2.82 | 0.28 | 9.03 |
| 6.50 | 6.50 | 0.00 | 0.00 |

In the discussion on Hogg's paper on the missing carbon, Albert Sauveur sought to explain the loss by means of the micro-structure of the hardened steel, and he has given the following results:†—

* *Journal of the Iron and Steel Institute*, 1896, No. II. p. 179 *et seq.*

† *Ibid.*, p. 197.

| Percent. of Carbon by Gravi- metric Analysis. | Micrographic Com- position per Cent. | | Marten- site Carbon per Cent. | Cemen- tite Carbon per Cent. | Missing Carbon in Percentage on— | | |
|---|---|-----------------|--|---------------------------------------|-------------------------------------|------------------|-----------------------|
| | Marten- site. | Cemen- tite. | | | Steel. | Total Carbon. | Martensite Carbon. |
| 0.10 | 85M + 15F | ... | 0.10 | ... | 0.04 | 40 | 40 |
| 0.14 | 100 | ... | 0.14 | ... | 0.04 | 29 | 29 |
| 0.21 | 100 | ... | 0.21 | ... | 0.10 | 48 | 48 |
| 0.25 | 100 | ... | 0.25 | ... | 0.12 | 48 | 48 |
| 0.30 | 100 | ... | 0.30 | ... | 0.13 | 43 | 43 |
| 0.35 | 100 | ... | 0.35 | ... | 0.18 | 51 | 51 |
| 0.39 | 100 | ... | 0.39 | ... | 0.16 | 41 | 41 |
| 0.45 | 100 | ... | 0.45 | ... | 0.20 | 44 | 44 |
| 0.50 | 100 | ... | 0.50 | ... | 0.22 | 44 | 44 |
| 0.62 | 100 | ... | 0.62 | ... | 0.21 | 34 | 34 |
| 0.70 | 100 | ... | 0.70 | ... | 0.35 | 50 | 50 |
| 0.75 | 100 | ... | 0.75 | ... | 0.43 | 57 | 57 |
| 0.84 | 100 | ... | 0.84 | ... | 0.49 | 58 | 58 |
| 0.92 | 95.65 | 0.35 | 0.90 | 0.02 | 0.51 | 55 | 57 |
| 1.00 | 98 | 2 | 0.89 | 0.11 | 0.50 | 50 | 56 |
| 1.25 | 94 | 6 | 0.85 | 0.40 | 0.51 | 41 | 60 |
| 1.50 | 90 | 10 | 0.81 | 0.69 | 0.40 | 27 | 49 |
| 1.64 | 87 | 13 | 0.78 | 0.86 | 0.31 | 19 | 40 |
| 1.70 | 86 | 14 | 0.77 | 0.93 | 0.35 | 21 | 45 |
| 2.40 | 74 | 26 | 0.67 | 1.73 | 0.30 | 12 | 45 |
| 3.10 | 62 | 38 | 0.56 | 2.54 | 0.28 | 9 | 50 |
| 6.50 | 3 | 97 | 0.03 | 6.47 | 0.00 | ... | ... |

Since the average per cent. in the last column is 47 (omitting the abnormal figures 29 and 34 it is 49 per cent.), Sauveur assumes that the missing carbon stands in a constant relation to the carbon of the martensite. This would agree very well with Howe's mean value in steel with 0.21 per cent. carbon after quenching above the critical zone (45 per cent.), as well as with the values obtained by Osmond and Werth (47 per cent. and 51 per cent.) with steel of 0.90 per cent. C.

Starting from Hogg's observation that quenched steel with 0.89 per cent. carbon (*i.e.* Arnold's sub-carbide Fe_{24}C) gives a solution of which the colour percentage is only 0.385 per cent., whilst the solution of the normal carbide (Fe_3C) yields 0.89 per cent. carbon, Saniter, taking Hogg's results as a basis, finds the following values:—

| Calculated Composition of the Hardened Steel. | | | Total Carbon per Cent. | Carbon in Hardened Steel Estimated by Colorimetric Method. | | Difference per Cent. |
|---|-----------------------------|------------------------------|------------------------|--|-------------|----------------------|
| Fe per Cent. | Fe ₃ C per Cent. | Fe ₂₄ C per Cent. | | Found. | Calculated. | |
| 88.7 | ... | 11.3 | 0.10 | 0.06 | 0.04 | - 0.02 |
| 84.2 | ... | 15.8 | 0.14 | 0.10 | 0.06 | - 0.04 |
| 76.3 | ... | 23.7 | 0.21 | 0.10 | 0.09 | - 0.01 |
| 71.8 | ... | 28.2 | 0.25 | 0.13 | 0.11 | - 0.02 |
| 66.1 | ... | 33.9 | 0.30 | 0.17 | 0.13 | - 0.04 |
| 60.5 | ... | 39.5 | 0.35 | 0.17 | 0.15 | - 0.02 |
| 55.9 | ... | 44.1 | 0.39 | 0.23 | 0.17 | - 0.06 |
| 49.2 | ... | 50.8 | 0.45 | 0.25 | 0.19 | - 0.06 |
| 43.5 | ... | 56.5 | 0.50 | 0.28 | 0.22 | 0.06 |
| 29.9 | ... | 70.1 | 0.62 | 0.41 | 0.27 | 0.14 |
| 20.9 | ... | 79.1 | 0.70 | 0.35 | 0.30 | 0.05 |
| 15.3 | ... | 84.7 | 0.75 | 0.32 | 0.32 | ... |
| 5.1 | ... | 94.9 | 0.84 | 0.35 | 0.36 | + 0.01 |
| ... | 0.5 | 99.5 | 0.92 | 0.41 | 0.41 | ... |
| ... | 2.0 | 98.0 | 1.00 | 0.50 | 0.50 | ... |
| ... | 6.35 | 93.65 | 1.25 | 0.74 | 0.78 | + 0.04 |
| ... | 10.7 | 89.3 | 1.50 | 1.10 | 0.98 | - 0.12 |
| ... | 13.05 | 86.95 | 1.64 | 1.33 | 1.20 | - 0.13 |
| ... | 14.1 | 85.9 | 1.70 | 1.35 | 1.27 | - 0.08 |
| ... | 26.25 | 73.75 | 2.40 | 2.10 | 2.13 | + 0.03 |
| ... | 38.4 | 61.6 | 3.10 | 2.82 | 2.79 | - 0.03 |

Here it is noteworthy that only two differences (and these very small falling within the possible errors of experiment) are positive, whilst all the others, including values from 0.06 to 0.14 per cent., are negative—a circumstance which would appear to indicate that the factor for reckoning the subcarbide has been taken somewhat too small.

Finally, J. E. Stead assumes that all carbon in hardened steel over 0.8 per cent. is present as Fe₃C, a combination which gives the normal colour, whilst the carbon up to 0.8 per cent. only gives a colour corresponding to 0.33 per cent. carbon.

From this hypothesis he calculates:—

| C. per Cent. | C. per Cent. as Estimated by Colour. | Calculated per Cent. | Difference. |
|--------------|--------------------------------------|-----------------------------|-------------|
| 0.80 | ... | 0.33 | ... |
| 0.84 | 0.35 | ... | ... |
| 0.92 | 0.41 | 0.33 + (0.92 - 0.80) = 0.45 | + 0.04 |
| 1.00 | 0.50 | 0.33 + (1.0 - 0.80) = 0.53 | + 0.03 |
| 1.25 | 0.71 | 0.33 + (1.25 - 0.80) = 0.78 | + 0.04 |
| 1.50 | 1.10 | 0.33 + (1.50 - 0.80) = 1.03 | - 0.07 |
| 1.64 | 1.33 | 0.33 + (1.64 - 0.80) = 1.17 | - 0.16 |
| 1.70 | 1.35 | 0.33 + (1.70 - 0.80) = 1.23 | - 0.12 |
| 2.40 | 2.10 | 0.33 + (2.40 - 0.80) = 1.93 | - 0.17 |
| 3.10 | 2.82 | 0.33 + (3.10 - 0.80) = 2.63 | - 0.19 |

The values here found are up to 1.25 per cent. carbon higher, but for higher carbon percentages lower, than those directly found.

At the Spring meeting of the Iron and Steel Institute in 1897, the author presented a paper on the estimation of the hardening and carbide carbon, in which he sought to separate the two carbonaceous residues *a* and *b* (see above). In continuation of this work * he came to the following conclusions:—

(1.) The estimation of carbide carbon (residue *b*) succeeds by the calorimetric method easily and safely.

(2.) The estimation of hardening carbon (residue *a*) only gives reliable results when a normal steel in a similar state of hardness is employed, because

(3.) The hardening-carbon of the hardened steel (above the critical point) colours the nitric acid solution much less strongly than the hardening carbon of naturally hard steel, or than such steel does when quenched below the critical temperature.

(4.) This leads to the conclusion, confirmed also by microscopic examination, that hardening carbon exists in two different forms, as martensite carbon (above the critical point) and as pearlite carbon (below the critical point).

(5.) The solution of the carbide carbon colours strongest, the solution of the total carbon (as a mixture of the first with the following) somewhat less strongly, that of the pearlite carbon still weaker, and, finally, that of the martensite carbon the least of all.

(6.) The proportionate depths of colour of the solution of the carbide, pearlite, and martensite carbon are as 10 : 8 : 5.

(7.) This relation gives us the means of estimating, at least approximately, the quantity of pearlite and martensite carbon.

According to our present experience, and especially in the researches of E. D. Campbell, which derive confirmation from the employment of the solution theory to iron and steel, these conclusions require modification in the following manner:—

We have, as is known, in iron carbon alloys carbon as such (either in closed molecules or as ions), and combined with iron as carbide ($n\text{CFe}_3$), which leaves it an open question whether

* *Stahl und Eisen*, 1897, No. 14.

Arnold's subcarbide is to be considered merely a solution of carbide in iron or as a molecular combination.

Now, as mentioned above, according to Campbell, the iron carbide appears to be in various polymers of the common formula, C_nFe_{3n} . The most important of these are: C_2Fe_6 , C_3Fe_9 , C_4Fe_{12} , and C_5Fe_{15} . In annealed steel with less than 1.3 per cent. carbon, C_4Fe_{12} prevails; with increasing percentage of carbon the amount of C_2Fe_6 increases, and hardened steel appears to contain larger amounts of the latter combination than the same steel in the annealed condition.

If one considers that the carbide of iron, according to Saniter, begins to dissociate at $800^\circ C.$, and considering further the curve given in Fig. 7 of the molecular weights of iron carbide in steel of from 0 to 0.9 per cent. carbon, as well as the curve shown in Fig. 6 of the missing carbon in steel, with 0.21 per cent. C, after quenching at different temperatures, we see that just at the point of transition between the martensite and pearlite a considerable polymerisation of the carbide takes place, whilst above Ar_2 , and apparently also about 100° below Ar_1 , the molecular weight becomes almost constant. Above Ar_2 the molecular weight decreases considerably, a phenomenon which, at least in part, may be connected with the beginning of the dissociation of the carbide.

According to the above-cited conclusions, however, we have, more especially from a chemical standpoint, to differentiate between three sorts of carbon of varying power as regards colour intensity:—

- (1.) Hardening carbon above the critical point with a colour intensity of 0.5 (martensite carbon).
- (2.) Hardening carbon under the critical point with a colour intensity of 0.8 (pearlite hardening-carbon).
- (3.) Carbide carbon with the colour intensity 1.0.

In the before-mentioned paper* the author worked out the percentage of these three forms of carbon in five samples of steel, and found:—

* *Stahl und Eisen*, 1897, No. 14.

| Samples. | Total Carbon. | Martensite Hardening Carbon. | Pearlite Hardening Carbon. | Carbide Carbon. |
|--|---------------|------------------------------|----------------------------|-----------------|
| | Per Cent. | Per Cent. | Per Cent. | Per Cent. |
| A. Annealed | 0.78 | ... | 0.14 | 0.65 |
| B. Annealed | 1.20* | ... | 0.128 | 0.95 |
| C. Cooled in ordinary way | 0.93 | 0.030 | 0.200 | 0.70 |
| D. Hardened by water-quenching | 0.93 | 0.358 | 0.157 | 0.414 |
| E. Cooled in ordinary way | 1.414 | 0.163 | 0.232 | 1.019 |

These figures offer a further confirmation of Campbell's views, but the application of the laws of solution to solid steel supports also the hypothesis that martensite contains iron carbide.

Steel with 0.93 per cent. carbon can, when in the fully hardened condition, contain 0.13 per cent. carbon as cementite, whilst experiment gives 0.414 per cent. carbide carbon, the excess ($0.414 - 0.13 = 0.284$ per cent.) must either be contained in the martensite or the hardening cannot have been quite complete.

On the other hand, the annealed samples *A* and *B* could not contain martensite, and, as a matter of fact, experiment showed no martensite hardening carbon.

We arrive, therefore, at the following conclusions:—

(1.) Annealed steel contains no martensite hardening-carbon, but (in pearlite) carbide carbon and pearlite hardening-carbon.

(2.) Hardened steel contains, besides the carbon contained in the very trifling amount of separated cementite (carbide carbon, and perhaps also pearlite hardening-carbon?) in the martensite, martensite hardening-carbon (possibly also carbide and pearlite hardening-carbon). From this it follows:—

(3.) That the iron carbide contained in pearlite is decomposed by cold dilute nitric acid in the cold into a part going into solution (pearlite hardening-carbon), and into a residue soluble at 80° C. (carbide carbon). The relation between the two appears to be one varying according to the percentage of carbon.

(4.) Whether the carbide contained in martensite by treatment with cold dilute nitric acid gives only the martensite hardening-carbon, or the two other mentioned forms of carbon,

* 0.17 per cent. of temper carbon.

remains undecided until further experiments are made. It is, however, possible.

If one compares this with Campbell's experiments, according to which in hardened steel C_2Fe_6 predominates, we arrive at the conclusion that the formation of martensite hardening-carbon (at least in the most prominent degree) must have this condition; and further, that in annealed steel with up to 1.3 per cent. C, in which C_4Fe_{12} predominates, the formation of carbide carbon must chiefly correspond thereto, and the supposition appears probable that the carbides C_3Fe_9 and C_5Fe_{15} must belong essentially to the transition curve of Fig. 6.

But Campbell's statement that steel with more than 1.3 per cent. carbon contains increasing quantities of C_2Fe_6 is also confirmed by a comparison of the samples C. and G., the latter steel containing more than five times as much martensite hardening-carbon as the former.

Whether the separated iron carbide exists as free cementite like that of the pearlite requires still further investigation, but a comparison of the samples C. and G., which have experienced similar heat-treatment, makes this improbable. Had the two samples been annealed they would have contained—

| | Sample C. Per Cent. | Sample G. Per Cent. |
|------------------------------------|------------------------|------------------------|
| Total carbon | 0.93 | 1.414 |
| Carbon in pearlite | 0.90 | 0.900 |
| Carbon in free cementite | 0.03 | 0.514 |

As a matter of fact there was found—

| | | |
|-------------------------------------|------|-------|
| Pearlite hardening-carbon | 0.20 | 0.232 |
| Carbide carbon | 0.70 | 1.019 |
| Together | 0.90 | 1.251 |

That is to say, that sample G. contains only about 0.2 per cent. less pearlite hardening-carbon and carbide carbon than was to be expected; the missing amount must be present as martensite hardening-carbon. This leads, however, to the conclusion that in all probability C_2Fe_6 prevails also in martensite, and that this combination probably prevails also in the free cementite, separated at a higher temperature from the martensite. The formation of C_3Fe_9 may be the beginning of the polymerisation taking place

at A_{r_1} , whilst the formation of C_4Fe_{12} appears to be characteristic of pearlite. The formation of C_5Fe_{15} may finally show itself at a temperature lying considerably below A_{r_1} .

Whether the carbide of the cementite separated at a higher temperature is likewise polymerised with decreasing temperature is doubtful. Sample G. makes this probable, but such polymerisation cannot go so far as in pearlite. Also, no information is yet available as to the colour intensity of the carbide decomposed into its ions or of austenite.

Further, the remarkable relationship between the colour intensity of the three often-mentioned forms of carbon, and the degree of polymerisation of the corresponding carbide, must be recognised, since both rise the one with the other.

This agreement is very striking when one compares the relative colour intensity of the forms of carbon with the formulæ of the carbides supposed, on the grounds above given, to chiefly prevail in them:—

| Form of Carbon. | | | | Formulae of the Prevailing Carbide. |
|-------------------------------|-------------------|-----|-----|-------------------------------------|
| Description. | Colour Intensity. | | | |
| Martensite hardening-carbon . | 0.5 | 1.0 | 2.0 | $2(CFe_3) = C_2Fe_6$ |
| Pearlite hardening-carbon . | 0.8 | 1.6 | 3.2 | $3(CFe_3) = C_3Fe_9$ |
| Carbide carbon . | 1.0 | 2.0 | 4.0 | $4(CFe_3) = C_4Fe_{12}$ |

Does one not feel obliged to take pearlite hardening-carbon, $3(CFe_3) = C_3Fe_9$, as of paramount importance, and from this to conclude that the colour intensity rises proportionately to the number of atoms of carbon present in the carbide molecule?

If we collect all that has been said in favour of the existence of three forms of combined carbon, we have—

1. Only a part of the combined carbon present is soluble in cold dilute nitric acid; another part only on warming.

2. Carefully annealed steel, which contains no martensite, gives a solution of hardening-carbon which possesses a colour intensity of 80 per cent. of that of the carbide carbon solution.

3. The colour intensity of hardened steel has in cold solution only 50 per cent. of that of carbide carbon.

4. The above facts agree perfectly with Campbell's observations ; and
5. With the size of the molecule as calculated by the solution theory.

The distinctions required in the above for the three sorts of chemically combined carbon are not only too detailed for practical use, but also are not quite correct, inasmuch as their appearance does not seem to be restricted to that morphological entity from which their name is borrowed.

It is possible to arrive at a more simple and more logically correct nomenclature ; by taking as a basis the colour intensity of the single carbon forms (about 1 : 1.5 : 2) a complete numerical relation is hereby obtained, as well as a striking analogy with Campbell's formulae.

The form of carbon with a

| | |
|--|--|
| Colour intensity 2 being designated as Bi-carbon ; | |
| " " 3 " " Tri-carbon ; | |
| " " 4 " " Tetra-carbon. | |

So that there would be

| |
|---|
| In martensite (especially when not alone) : Bi-carbon . |
| In free cementite : Bi-, Tri-, and Tetra-carbon ; |
| In pearlite : Tri- and Tetra-carbon. |

V.—*Summary.*

The above considerations lead to results which, at a first glance, appear very complicated, and which recognise the existence of what many might think an alarming variety of compounds in iron. On the other hand, they allow everything to be considered which takes place in the interior of the metal, from a homogeneous point of view, and we are able thereby to obtain a clear homogeneous picture, which brings us nearer to a full understanding of many of the difficult and puzzling phenomena.

First, we find that carbon is dissolved as such in pure iron by a sufficiently high temperature, and we can, in accordance with Roberts-Austen's curve (Fig. 5), supplement our earlier statements as to the solubility of this element in the following manner :—

| Temperature in °C. | The Saturated Iron Carbon Solution contains Parts of Carbon— | |
|-----------------------|---|--------------------------|
| | In 100 Parts of the Solution. | In 100 Parts of Iron. |
| 3500 | 40.0 | 66.67 |
| 1260 | 5.5 | 5.82 |
| 1200 | 5.0 | 5.26 |
| 1142 | 4.5 | 4.71 |
| 1130 | 4.3 | 4.49 |
| 1030 | 1.5 | 1.54 |

Further, we find that the molecule of the dissolved carbon (at least in alloys poor in carbon), between 1600° and 1300° C., consists of two atoms; that it increases with decreasing temperature; and that at about 1150° C. nearly equal amounts of two and three atom-molecules are present in the solution.

At a still lower temperature there is in the solution, besides a certain amount of free carbon increasing with the content of carbon present, iron carbide. At first this latter remains in solution with the free carbon (austenite). If, however, its quantity increases above a certain amount, the alloy separates into two parts; in the one the free carbon (the austenite) prevails, in the other the carbide of iron (martensite) prevails. With falling temperature the amount of the iron carbide increases, as also does the martensite, whilst the quantity of the austenite decreases, until at length only martensite is present.

By further cooling in the case of low carbon alloys, only pure iron (ferrite) separates itself from the martensite, whilst in high carbon alloys a separation of cementite results. Iron carbides, which at this temperature contain much C_2Fe_6 , at lower temperatures, however, are wholly polymerised.

Finally, at a lower temperature the transition of the martensite into pearlite takes place with simultaneous rapid polymerisation of the carbide, in which now C_4Fe_{12} prevails. Other elements dissolved in iron behave exactly in a similar way. Silicon, for example, also appears to be an element in solution at a high temperature, and its molecule (in relation to the number of atoms contained in it) seems to possess about the same size as carbon. But at a lower temperature silicon combines with iron, and we have a solution of this combination (Fe_3Si) before us,

which finally also separates out. The separation of other combinations takes place in an analogous manner (Fe_3P , &c.), whilst still others, such as ferro-tungsten Fe_3W , even at ordinary temperatures, appear to be for the larger part dissociated.

Those elements whose alloys produce isomorphous mixtures with iron play a somewhat different rôle, as, for example, manganese (and nickel). Such elements influence each other in such a manner that each influences the molecular size according to the proportion in which it is mixed, yet in the case of pure alloys of this description neither one nor the other of the constituents separates. Other elements, on the contrary, behave themselves like a single, simple solution medium, and their influence on the solution phenomena of foreign elements depends upon the solubility relation of the latter in the two components of the first.

Thus it appears, for example, that manganese exercises no appreciable influence on the molecular size of the dissolved elements carbon and silicon. On the contrary, the power of solution of manganese is, as compared to these two elements, much greater than that of iron.

Steels rich in manganese do not show any separation of martensite and austenite. This may be put down either to the greater solution power of manganese, or, with more probability, to the fact that manganese hinders the formation of the carbide or retards it. For the latter conjecture the fact may be cited that the formative element hereby appearing (according to a courteous communication from Osmond) approaches nearer to austenite than to martensite.

Silicon and phosphorus are separated as polymeric silicides and phosphides. Now, since the latter element is present in at least two forms,* it appears probable, at least for this element, that besides the separated, there must also exist in iron a dissolved depolymerised phosphide, which is similar to martensite (or, perhaps, more correctly present in martensite). This form may be called "hardening phosphorus," and is easily decomposable by acids (like the corresponding carbide).

Further, we must compare the relationship between the iron

* Jüptner, "The Influence of Phosphorus on Cold-Shortness," *Journal of the Iron and Steel Institute*, 1897, No. 1.

and the silicate as against the oxide and sulphide. In the first place, slag appears to be as good as insoluble in iron; but, on the other hand, the oxides (FeO and MnO) and the sulphides (FeS and MnS) are readily soluble, and are first separated in the critical zone. (See Osmond's recalcrescence observations and those of Arnold.) In slag-free metal the separation of this combination takes place first in the solid state; but the case is otherwise in the simultaneous presence of slag, in which these are more soluble than in iron. Here the mass of the oxides and sulphides divide themselves in proportion to their solubility between the metal and the slag, and one succeeds thereby in separating them from the metal. Silica appears to behave in a similar manner.

Recently poured steel gives a bad material by the simple addition of ferro-silicon. If, however, one adds with or after the ferro-silicon some ferro-manganese also, a manganese silicate is produced, which readily separates from the fluid metal, and a good material results.

These reactions lead us to the consideration of the chemical changes which take place in the interior of the non-molten metal. Some of these, such as polymerisation, depolymerisation, the dissociation of the carbide, &c., have been already described; another series of similar reactions must now be mentioned.

The author has examined* four puddled balls and the wrought-iron produced from them, and found:—

| Constituent. | I. | | II. | | III. | | IV. | |
|-----------------------------|----------|---------------|----------|---------------|----------|---------------|----------|---------------|
| | Ball. | Wrought Iron. | Ball. | Wrought Iron. | Ball. | Wrought Iron. | Ball. | Wrought Iron. |
| Carbon . . . | 0.207 | 0.121 | 0.287 | 0.1271 | 0.1162 | 0.101 | 0.2806 | 0.1204 |
| Silicon . . . | 0.1076 | 0.074 | 0.132 | 0.094 | 0.1634 | 0.069 | 0.207 | 0.133 |
| Manganese . . | 0.644 | 0.513 | 0.587 | 0.558 | 0.628 | 0.581 | 0.706 | 0.658 |
| Sulphur . . . | 0.005 | 0.004 | 0.005 | 0.006 | 0.006 | 0.005 | 0.018 | 0.012 |
| Phosphorus . . | 0.0331 | 0.0214 | 0.0373 | 0.0271 | 0.0684 | 0.0484 | 0.1208 | 0.1037 |
| Copper . . . | trace | trace | trace | trace | 0.003 | 0.002 | 0.004 | 0.003 |
| Cobalt and nickel . . . | ... | ... | ... | ... | ... | ... | ... | ... |
| Metallic iron . | 98.8923 | 99.1026 | 98.8217 | 99.1538 | 98.8704 | 99.0436 | 98.3916 | 98.5859 |
| Slag { SiO_2 . . . | 0.018 | 0.040 | 0.025 | 0.042 | 0.012 | 0.054 | 0.018 | 0.048 |
| Fe_2O_3 . . | 0.189 | 0.156 | 0.100 | 0.088 | 0.161 | 0.095 | 0.242 | 0.319 |
| Mn_2O_3 . . | 0.011 | 0.009 | 0.005 | 0.004 | 0.009 | 0.005 | 0.012 | 0.017 |
| Total . . . | 100.0000 | 100.0000 | 100.0000 | 100.0000 | 100.0000 | 100.0000 | 100.0000 | 100.0000 |

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, 1894, p. 237.

I. and II. were produced from charcoal pig; III. and IV. from coke pig iron.

It is evident that the amount of slag must be smaller in the finished product than in the ball, and this is the case in I. and III. :—

| Slag. | Ball. | Finished Metal. | Difference. |
|--------------|-----------|-----------------|-------------|
| | Per Cent. | Per Cent. | Per Cent. |
| I. | 0·218 | 0·205 | - 0·013 |
| II. | 0·130 | 0·134 | + 0·004 |
| III. | 0·182 | 0·154 | - 0·028 |
| IV. | 0·272 | 0·384 | + 0·112 |

In Sample II. the amount of slag remains unaltered, and in IV. the finished iron shows more slag than in the ball, a circumstance which is explained by the difficulty of obtaining a reliable average sample of the ball.

It is a striking fact that the silica in the finished iron is throughout considerably higher than it is in the corresponding ball :—

| SiO ₂ . | Ball. | Finished Metal. | Difference. |
|--------------------|-----------|-----------------|-------------|
| | Per Cent. | Per Cent. | Per Cent. |
| I. | 0·018 | 0·040 | + 0·022 |
| II. | 0·025 | 0·042 | + 0·017 |
| III. | 0·012 | 0·054 | + 0·042 |
| IV. | 0·018 | 0·048 | + 0·030 |

Thus the composition of the slag in the finished iron is always more acid than that in the ball :—

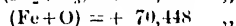
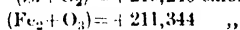
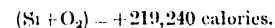
| No. | Description of the Slag. | SiO ₂ . | Fe ₂ O ₃ . | Mn ₂ O ₃ . |
|--------|--------------------------|--------------------|----------------------------------|----------------------------------|
| | | Per Cent. | Per Cent. | Per Cent. |
| I. } | Puddled ball | 8·25 | 86·69 | 5·06 |
| I. } | Finished iron | 19·51 | 76·09 | 4·40 |
| II. } | Puddled ball | 19·23 | 76·92 | 3·85 |
| II. } | Finished iron | 31·24 | 65·67 | 2·99 |
| III. } | Puddled ball | 6·59 | 88·46 | 4·95 |
| III. } | Finished iron | 35·06 | 61·69 | 3·25 |
| IV. } | Puddled ball | 6·61 | 88·97 | 4·42 |
| IV. } | Finished iron | 12·50 | 83·09 | 4·41 |

Thus, whilst on the one hand the amount of slag must be lessened by means of the mechanical work, on the other hand an increase of silica takes place (both relative and absolute), which can only be partly explained by that taken up from the bottom, &c. When we consider the variation which the percentage of silicon has undergone:—

| | Puddled Ball. | Finished Metal. | Difference. | |
|--------------|------------------|--------------------|-------------|-----------------------------|
| | | | Silicon. | Corresponding to Silica. |
| | Per Cent. | Per Cent. | Per Cent. | Per Cent. |
| I. | 0.1076 | 0.0740 | - 0.0336 | 0.0720 |
| II. | 0.1320 | 0.0940 | - 0.0380 | 0.0814 |
| III. | 0.1694 | 0.0690 | - 0.1004 | 0.2151 |
| IV. | 0.2070 | 0.1330 | - 0.0740 | 0.1586 |

we find a considerable diminution of this element, which can only be explained by its oxidation into silica. Thus it is noteworthy that in general an increasing rise in the slag silica corresponds to an increasing fall in the silicon.

This formation of silica from the silicon of the metal can, however, be well explained by a simultaneous reduction of the metallic oxides in the slag (especially of ferric and ferrous oxides), an hypothesis which is strengthened by a comparison of the heat of formation of the compounds involved (referred to their molecular weight), which is higher for silica than for ferric or ferrous oxide:—



The remaining elements, especially carbon, show like alterations from similar causes.

By an analogous treatment of ingot iron the same phenomena take place, and these intermolecular reactions are those which have been here dealt with.

They have also their practical importance, since they allow of an easy recognition between the red-shortness due to a slight amount of occluded oxide, and the red-shortness due to sulphur, by strongly forging the metal under consideration at a white

heat. The former defect disappears by this treatment, or at least is lessened, whilst the latter remains unaltered.

Coming to a conclusion, it may be mentioned that at present one distinguishes in the metallography of iron only the often-mentioned formative elements. From the present state of our investigations this cannot, however, long remain the case. It will be necessary to distinguish between the cementite consisting of iron carbides from that which has a totally distinct composition, and which occurs in special steels (chromium steel, &c.). In the same way a distinction between the austenite of ordinary steel and that in manganese steel must be faced if further inquiry shall yield exact results. The naming of these substances must be left to the distinguished investigators in this field, as only they are entitled to do it.

CORRESPONDENCE.

Mr. F. OSMOND desired to express his thanks to Baron Jüptner for having been good enough to take into serious consideration the remarks he had contributed to the discussion of his previous papers. The author's aim to connect the works of physico-chemists with those of metallurgists deserved unqualified approval. A research of that kind showed not only the results obtained, but also the attempts that had still to be made to complete them, and would point out the right path to those who took it as a guide.

Dr. ALFRED STANSFIELD wrote that he had been very much interested in the paper by Baron Jüptner on the solution theory of iron and steel, as well as in previous papers by the same author. These papers were very valuable, as they helped to interpret the results of experiments, and indicated the direction in which further research was required.

In the present paper, however, there were some lines of argument that did not appear to him to be quite correct, and some other parts of the paper were based on rather slender experimental evidence, so that it was difficult to speak decidedly about them.

With reference to the austenite curve in Fig. 5, if, as Baron Jüptner suggested, it divided the region of free carbon from that of combined carbon, it would not be able to cross the line SE without experiencing a change of direction, for SE indicated the separation of combined carbon from solution in the iron; either the austenite line or the line SE would have to be modified. The method of calculating the atomic weight of a dissolved body by the lowering of the fusing-point of the solvent had been applied in the paper to cases in which the solvent remained solid at temperatures above that at which the dissolved body fell out of solution, but the lowering had in each case been calculated from the *melting-point* of the pure solvent, and the *latent heat of fusion* of the solvent was used in the calculations. On pages 212 and 213, for example, the fusing-point of the steel was not really depressed to points on the austenite curve (though this was implicitly assumed in the calculation), and therefore it

was not fair to use the *latent heat of fusion* of iron in the calculation. The same criticism applied to the calculations in Section III., and also, as it was not known that the points of arrest had any connection with the melting-point of iron, it was impossible to say whether this temperature could be used in the calculations. Under these conditions the unsatisfactory nature of the results was not surprising.

It was possible, as Sir William Roberts-Austen had mentioned in his presidential address, to employ points of molecular change for calculating the molecular weights of carbon or other elements in solid solution in iron; but suitable substitutes for the temperature and latent heat of fusion of iron must generally be used in the calculations. This was too large a subject to be fully discussed at present, but he hoped to submit a paper dealing with it at the next meeting of the Institution.

With reference to the statement at the top of page 211 in the paper, it might be mentioned that, as iron at 1100° C. would hold about $1\frac{1}{2}$ per cent. of carbon in *solid solution*, it seemed probable that there could be no *liquid eutectic* in steel until at least $1\frac{1}{2}$ per cent. of carbon had been added, because any smaller amount would solidify with the iron.

Dr. Stansfield regretted that he had not time to suitably discuss the author's very interesting contribution to the study of the "Missing Carbon," and that his contribution to the discussion had been mostly limited to the thankless task of criticism. He felt that, by introducing mathematical considerations in his papers, Baron Jüptner had made a very valuable addition to the study of iron and steel.

Sir JOSEPH PEASE, Bart., proposed that the best thanks of the Iron and Steel Institute be and are hereby tendered to the President, Council, and Secretary of the Institution of Civil Engineers, for the use of their room, and for the facilities otherwise afforded for the present meeting.

Mr. JAMES RILEY, Vice-President, had very great pleasure in seconding the proposal made by Sir Joseph Pease. As year by year passes by, and we again and again participate in the kindness of the President, Council, and Secretary of the Institution

of Civil Engineers, he was sure the feeling of indebtedness grew, and that we could not do other than record our heartiest thanks to them.

The vote was passed by acclamation.

Mr. W. WHITWELL, Hon. Treasurer, then said : I rise with very much pleasure to propose the resolution which we always pass on all occasions when we are well satisfied with what we have been listening to, and with the information we have gained, and especially with the conduct of our chairman. I beg to move, "That the best thanks of the members be given to the President for his able conduct in the chair." If it were possible to say anything more complimentary to-day than we said yesterday, I would say it, but I think you will all agree with me that it is not needed. We have in our new President, Sir William Roberts-Austen, a President who has shown in the past how much he deserved the highest honour that we could bestow upon him. We have in him one who has distinguished himself in science in a remarkable way. We feel as we sit under him that we are sitting under a master, one who knows much about the various questions which come before us. We feel exceedingly grateful to him for his conduct in the chair, and we feel that under his excellent guidance we shall not only be kept in order, but we shall have an amount of information in our papers during his presidency that will be really improving to our minds. We shall leave this meeting to-day with a sense that we have learned something that we did not know before, and that we shall have still a great deal more to learn when we take the papers home and consider them. On your behalf, and on behalf of all the members who have not been present, I have very much pleasure in proposing a resolution thanking our President for his exceedingly able conduct in the chair.

Mr. W. BEARDMORE, Member of Council, seconded the resolution, which was carried by acclamation.

The PRESIDENT having expressed his acknowledgments, the meeting terminated.

THE ANNUAL DINNER.

The members of the Institute dined together in the Grand Hall of the Hotel Cecil on Thursday evening, May 4th, the chair being occupied by the President, Sir William Roberts-Austen, K.C.B., D.C.L., F.R.S. The President was supported by a number of distinguished guests, and by most of his colleagues on the Council. Amongst the noblemen and gentlemen present were His Excellency the Swedish and Norwegian Minister, the Right Rev. the Lord Bishop of Rochester, the Right Honourable the Lord Welby, G.C.B., the Right Honourable the Lord Strathcona and Mount Royal, G.C.M.G., the Right Honourable the Lord Lister (President of the Royal Society), the Right Honourable Sir Bernhard Samuelson, Bart., Past-President, the Honourable E. Lyulph Stanley, the Honourable Sir Charles Fremantle, K.C.B., Sir Frederick Bramwell, Bart., Sir John Evans, K.C.B., General Sir Henry Brackenbury, K.C.B., K.C.S.I., Sir William H. White, K.C.B. (President of the Institution of Mechanical Engineers), Sir John Wolfe Barry, K.C.B. (Chairman of Council of Society of Arts), Sir Norman Lockyer, K.C.B., Sir Lowthian Bell, Bart., Past-President, Sir James Kitson, Bart., M.P., Past-President, Sir David Dale, Bart., D.C.L., Past-President, Sir John G. N. Alleyne, Bart., Vice-President, Sir William T. Lewis, Bart., Vice-President, Sir Edward H. Carbutt, Bart., Sir Benjamin Hingley, Bart., Sir Alfred Hickman, M.P., Sir John J. Jenkins, M.P., Sir A. Seale Haslam, Sir Henry B. Robertson, Sir E. Leader Williams, Sir Joseph Leigh, Colonel Sir Howard Vincent, M.P., General H. le G. Geary, C.B., General F. T. Lloyd, C.B., Mr. Horace Seymour, C.B. (Deputy-Master and Comptroller of the Royal Mint), Mr. W. H. Preece, C.B. (President of the Institution of Civil Engineers), Colonel E. Bainbridge, C.B., Professor Michael Foster (Secretary of the Royal Society), Professor Rücker (Secretary of the Royal Society), the President of the Institute of Chemistry, the President of the Institution of Electrical Engineers, the President of the Society of Chemical Industry, the President of the Institution of Mining and Metallurgy, Mr. Edward Windsor Richards, Past-President, Mr. Edward P. Martin, Past-President, Mr. William Whitwell, Honorary Treasurer, Mr. James Riley, Vice-President, Mr. W. H. Bleckly, Vice-President, Mr. Andrew Carnegie, Vice-President,

Mr. Arthur Keen, Vice-President, Mr. S. R. Platt, Mr. R. A. Hadfield, Mr. William Beardmore, Mr. David Evans, Mr. A. Tannett Walker, Mr. F. W. Webb, and Mr. Adolphe Greiner.

The PRESIDENT, in submitting the toast of "Her Majesty the Queen," said that he did so under somewhat exceptional circumstances. They rejoiced to think that Her Majesty the Queen was on her way home to her own people. They were glad to think that she had been gaining health and strength in the hospitable and lovely country which was so near our shores, but they would be thankful to feel that Her Majesty was once again in the midst of her devoted people. The progress of the Iron and Steel Institute had been one of the main features of Her Majesty's glorious reign, and the Queen had been pleased to recognise this fact by accepting the Institute's Gold Medal. He would only add that the attributes they usually associated with steel—strength, rigidity, and endurance—were precisely those they would choose were it necessary for them to express their devotion to the throne and to the person of Her Majesty the Queen.

The PRESIDENT next gave the toast of "The Prince and Princess of Wales, and the other Members of the Royal Family." He said they could naturally dwell with special interest on the name of His Royal Highness the Prince of Wales, who was an honorary member of that Institute, and who had always shown his interest in science, and in industry in every possible way. He need not remind them of the great interest which His Royal Highness took in the forthcoming Paris Exhibition.

Mr. HORACE SEYMOUR, C.B., then proposed "The Navy and the Army." He said the history of the navy was a record of unbroken success. At any rate, it would require the memory of an antiquarian to recollect or to fix a date in which we were defeated in any general engagement, and, perhaps, in any single engagement. The record of the army was hardly second to that of the navy, and recent operations had shown them how successfully the present representatives, both in men and in officers, were able to carry out operations requiring great skill with very great success. He might congratulate Sir William Roberts-Austen on the representatives of the army and the navy whom he had secured that evening. Sir William White and Sir Henry Brackenbury were both men who had a world-wide reputation in their respective spheres. Both of them had one thing in common—probably

many things in common—but one thing especially interesting to those assembled, for both took a considerable interest in all operations connected with steel and iron, and that was, of course, of considerable interest to the members. They had also, perhaps, a point which was antagonistic, because Sir William White was engaged in producing ships and Sir Henry Brackenbury was probably thinking of how to destroy them. Between them they would always, at any rate, promote the interests of the members of the Institute, which was the chief thing they had to think of that evening.

Sir WILLIAM H. WHITE, K.C.B. (Director of Naval Construction and Assistant Controller of the Navy), in reply to the toast, said it was always a pleasant thing to be a guest of the Institute—a pleasure which he had enjoyed on many occasions. He had no claim to respond for the toast, which referred to the *personnel* of the navy, and he regretted that there was not a single naval officer present. If he should be invited next year, he hoped they would invite a real live admiral, so that he should not have to undergo the anxiety of making a speech. Of course he quite understood how the *matériel* of the navy should have a great interest for the members. Men could fight in very poor ships, and they had been known to fight in vessels that had been improvised into ships of war. While it was true that ships of some kind must be used to convey fighters into action, it was undoubtedly true that the issue of the contest would always be determined by the quality of those who were doing the fighting. He did not say that that should be a reason for asking the officers and men of the navy to face unequal odds. It was our place as a nation to send those who carried our honour and maintained our traditions into action in ships as fine as could be produced by the mechanical and metallurgical talent of the country. But first and foremost, in the future as in the past, the standing of the British navy must be determined by the quality and the conduct of its fighting men. Standing there in the absence of the true representatives of the navy, but having spent his life among them, he said, without the least fear, that there never had been a time in the history of the navy when the *personnel* stood higher than it did at the present time. To their courage, skill, and daring were added intelligence, culture, and professional knowledge such as their predecessors never possessed, nor, perhaps, were called upon to possess. The navy of this country owed to the Iron and Steel Institute a great debt. To the work done by the members of the Institute they were greatly indebted for the progress made, which had kept them, as they hoped, in the fore-front of the navies

of the world. Whenever a demand had been made upon the members, they had responded, whether in the form of new material or increased output; but in other countries there was a limit put to their resources. Here private capital and private enterprise had never failed to respond to the appeal of the Government. At the present time in many directions a large expansion of our productive powers was being made in order to meet the special demands of the moment. That was particularly true in the armour-plate manufacture of this country. Advances which had been cosmopolitan in their character and in their origin had been made, and those who had the conduct of affairs found it necessary to embark in large expenditure in order to fulfil new conditions. He thought the circumstances deserved mentioning, and although he hoped and believed there would be an adequate commercial return for this kind of investment, still the fact remained that the risk was taken, and that the private enterprise of this country had no mean share in maintaining the navy in the forefront of the world. If he were permitted, he would like to make one remark with reference to the President's address that day. The President had very justly said that the public interest and feeling about the navy in this country had been largely influenced by the writing of that distinguished American officer, Captain Mahan. The statement was perfectly true. It was perfectly true that to the magic of Captain Mahan's style and the charm of his writing was due in no small measure the public interest which existed. He, however, took exception to the statement that the great movement which marked the last twenty years in this country was due to that writing. It began in quite another way. It was a revival of a sentiment as old as the nation. No great Englishman had failed to note and to teach that the future of this country, its progress as a nation, and the maintenance of its power, were rooted in our supremacy at sea.

General Sir HENRY BRACKENBURY, K.C.B., K.C.S.I. (Director-General of Ordnance), replying on behalf of the army, said we had a very small army as compared with the great armed hosts of the other Powers of Europe. We had always in the field in those wars against savage nations, in which alone we had been engaged for the last forty years, very small bodies of troops in comparison with the masses that were brought against us; and he thought they would all admit that the smaller our army was the more necessary was it that it should be perfect, not only as regarded its *personnel* but its weapons; and for those weapons they were almost entirely dependent upon steel. They had the

money, happily, wherewith to get the best weapons, and the members of the Institute had the brains and enterprise to supply them with the best obtainable. The army might in the future depend upon that; and a glance back at the enormous strides which had been made in connection with steel in the years during which he had served in the army was enough to give him that confidence. When he thought of how little was known of steel at the time when he first began to learn anything about it from Dr. Percy, some forty years ago, as compared with what was known now, it seemed to him that almost a miracle of knowledge had been accomplished. They all knew the story of Andrea Ferrara, the great sword-maker, and how he was said to have murdered his apprentice for having tried to find out the secret of making his swords. He remembered speaking to Mr. Latham, the representative of Wilkinson & Sons, the sword-makers, about that, and Mr. Latham said he had no doubt that the story was true. Mr. Latham believed that Ferrara always made his swords in the dark, and the secret of his success was the exact colour of the heat at which he tempered his steel, and finding his apprentice concealed in the cellar in order to discover the secret, Ferrara instantly killed him. But if Ferrara knew that it was only when his steel was tempered at an exact heat that he got the perfection that he did, Ferrara had not the slightest idea why that particular heat gave him that perfect weapon, nor had he the slightest knowledge of what took place in the steel at that temperature so treated. Let them look at the extraordinary knowledge that they had now gained of steel, and how enormously that had been increased by that microphotography with which the name of their President had been associated in Austenite—one of those compounds which had been discovered in steel; that wonderful discovery which had enabled them now to know exactly what takes place in steel under different kinds of treatment. It seemed to him that just as a great musician reading the written score of an opera hears in his brain every note of every instrument in the orchestra that would be playing it, were it being played, so they now, when they looked at one of those microphotographs of an infinitesimally small fragment of steel, knew as exactly as if they had seen the various processes, the constitution of that steel, and the treatment which the steel had undergone. With their permission he would give an instance of the practical value of that microphotography to the services. A couple of years ago, when he was President of the Ordnance Committee, they received the news that a large gun had burst on board one of Her Majesty's ships. It was one of a batch of guns which had been made all about the same time, and naturally the bursting of this one gun gave rise to great anxiety among

the navy as to what might happen to the other guns. They applied to Sir William Roberts-Austen through their experts, Sir Frederick Bramwell and Sir Benjamin Baker, and Sir William gave them microphotographs of a portion of the steel from the fractured part of the gun. They had the chemical and the mechanical tests of the steel before it was made, and they knew the treatment to which the steel had been put, and their experts were enabled to say with perfect confidence, after examining those microphotographs, what were the causes of the fracture of the steel, and that it was due to the steel having been of a quality which now would not be accepted for gun manufacture; and they were able also, by examining all the tests to which all the other guns had been subjected which were made about the same time, to predict with perfect confidence that there was no danger of such a bursting in any of the other guns, and that the navy might continue to use them with perfect safety. That showed the practical advantage to the Ordnance Department of this discovery.

There was a very striking passage in one of the books of the President that always seemed to him of great value to the soldier, namely:—“That although it might not be possible to transmute metals, it was easy so to transform them by very slight influences that, as regarded the special service required from them, they might behave either usefully or entirely prejudicially.” That was of vital importance in connection with gun-steel, and also with projectiles. There were three things he wanted the members to turn their attention to. The first of these was connected with the subject which Sir William Roberts-Austen had recently treated in a paper that was of the most intense interest to him (the speaker) and to all who were engaged with him on this subject, and which was read before the King of Sweden last autumn, namely, erosion in the tubes of guns. This subject was of vital importance to the Ordnance Department, where they were endeavouring to overcome erosion as far as it might be possible, by ascertaining whether any different kind of propellant than cordite, or any alteration in the constituents of cordite, would enable them to get over this difficulty. But he felt there was another way in which the Ordnance Department could be helped, namely, by their studying the best method of treating steel, so as to prevent its being eroded in the terrible way in which it was now eroded under the action of these heated gases. There, again, the President had brought microphotography to their aid, and had taught them already some very interesting facts in connection with the action of the gases on the bore of the gun. The second thing he invited the attention of the Institute to was the material of which their projectiles were to be made for the

piercing of armour-plates. Here, again, Hadfield's and Firth's and other great firms were engaged in doing their utmost to get the best material, and here also the scientific method of study ought to be found very useful. The third thing the Ordnance Department wanted was the best possible kind of plate for gun-shields. In helping the Ordnance to attain these things the members would be helping the army of England and their country. In asking them as men of peace to help to develop these terrible weapons of war, it might seem that he was doing what was rather a brutal thing; but he really did not think so. It was an established fact that when the energies of the iron and steel-makers of this country were devoted to making only swords and battle-axes and chain-armour, wars were far more constant and bloody than they were now. It really was the case that, *pari passu* with the development and improvement of weapons of destruction, wars had been less frequent and the numbers of men killed and wounded in proportion to combatants had diminished. Therefore he hoped that when the Institute had arrived at such absolute perfection in the manufacture of destructive weapons that no one man or no one army would possibly be able to stand up against any other man or any other army, then they would see that which they all longed for, and which he was afraid even the Conference at the Hague would not bring about, namely, the reign of universal peace.

"The Houses of Parliament" was proposed by Professor A. W. RÜCKER (Secretary of the Royal Society), who said that his qualifications for speaking on this subject were chiefly negative, for he was a defeated candidate for Parliament, and since then, having become a Civil servant, his tongue was tied. But he might say that individuals and great societies and the State could do much to make the relations between science and industry closer and more useful. Only that day had the Royal Society appointed the first governing body of the National Physical Laboratory, and among the members of that body was a representative of the Iron and Steel Institute whom they were proud to place there. In this case the impulse of late years was due to Professor Oliver Lodge. It was then taken up by the Royal Society and the British Association, and pressed upon the Government with a force which no single individual could effect; and after that the Government promised to apply to the House of Commons for a small but substantial endowment to enable them to carry on the work. The success of such an institution depended upon such societies as theirs. The governing body were anxious to make researches, not only in pure

science, but in the standardising of instruments, and in many other directions which might be useful to those engaged in industry. It was for the members to show them the way in which such an institution would be most useful, and they hoped that Englishmen might be proud of the National Laboratory which they were about to establish.

LORD WELBY, G.C.B., in acknowledging the toast on behalf of the House of Lords, said they heard daily that their pre-eminence in commerce was being tested by keen and skilled competition. He saw no reason for any pessimistic forecast on that account. He believed that England would make, as she had made, and was making now, her own pre-eminence secure; but if we were able to attain that end, it would be due chiefly to those great teachers in scientific experiments and research whose hospitality they were enjoying that day. The leaders among those teachers should find their places in the House of Lords, which at all events should be representative of science and of art; and he thought the House of Lords was proud to find among its members such illustrious men as Lord Lister, Lord Kelvin, and Lord Armstrong. Perhaps he should only echo what would be in all their thoughts, that besides these illustrious names there was room for more, whose names would rather add to than borrow lustre from the House of Lords. As an old Civil servant, he wished to express his pleasure at seeing Sir William Roberts-Austen in the chair. The Civil Service was a body of great *esprit de corps*, and was duly jealous of its credit and honour, and past and present members of the Civil Service alike felt pride and pleasure in seeing Sir William in the chair of the Iron and Steel Institute. He begged to tender to their President his hearty congratulations, and the Civil servants all felt that the honour which was conferred upon Sir William had some reflection upon themselves.

SIR ALFRED HICKMAN, M.P., replying for the House of Commons, said he was not surprised that the members of the Iron and Steel Institute should toast the Houses of Parliament, for they had devoted most assiduous and almost embarrassing attention to the affairs of the trades in which they were engaged. Parliament had given them a Factory and Workshop Act to regulate their arrangements with their ironworkers, and Mines Regulations Acts with their miners, and an Act which provided for the wounded and killed in the industrial battle. Parliament even proposed that miners should not injure their health by being more than eight hours at one time underground, though a British miner only produced one-half as much coal per man per annum as in

the United States, and at about double the cost. Then a grandmotherly Government proposed to choose for them engine-tenders and boiler-tenders, and examine into their capacity and character. Then it had been found that the Workmen's Compensation Act had given rise to a great amount of litigation, and a bill was before the House of Commons to stop all difficulties of that kind. This bill provided that in future no employer should be able to plead any defence whatever against any claim which might be made by any one of his workmen. The bill went as far as that the employer would not be able to plead that he was not his workman, or even that there was not an accident at all. But there was one crowning mercy more, and that was a bill which provided that they should adopt American methods of coupling their railway waggons. By the adoption of this appliance they would not increase the accidents to their workmen more than eight or tenfold, and they would be able to acquire the automatic couplings at the mere nominal cost of eight or ten millions sterling. After that it was no wonder that the Iron and Steel Institute should toast the Houses of Parliament.

The next toast was that of the "Kindred Societies," proposed by Sir JAMES KITSON, Bart., M.P. (Past President). He said that he proposed the toast with the greatest satisfaction, knowing the high position the industry they represented held in the nation, and knowing that they as an industry had done their full duty to the country. They had been accused in Consular Reports of being dilatory in not sending out their travellers, and not wrapping their goods up in the particular colour of paper which foreign nations desired. They had also been accused of not availing themselves of the opportunities of scientific culture and of scientific assistance which the great societies he had to propose offered to them. Well, they had been accused wrongly. Their President was a Fellow of the Royal Society, and they had on their Council other Fellows of the Royal Society, and they had leaned upon them and given them the posts of honour in their Institute, because they knew it was only with their assistance, and with the knowledge they taught them, that they could hope to hold their position in the world. In coupling with the toast Lord Lister, the President of the Royal Society, he mentioned a man who was the greatest living benefactor of humanity. The great discoveries in medical science which he had made had lessened the horrors of the accidents and mitigated the sufferings of those whom they employed. He had also to couple with the toast the name of Mr. Preece, the President of the Institution

of Civil Engineers. He was reminded in mentioning Mr. Preece's name that last year he had the honour of speaking at that table in the presence of his Excellency the Minister of Sweden, and then they were preparing for a visit to Sweden, where they were received in a magnificent and hospitable manner. They were welcomed not only by the people, but his Majesty the King of Sweden literally took them by the hand and welcomed them as guests into his home. They learnt in Sweden that the great forces of power in nature, in water, were being gathered up, and by the help of the electrical engineer (that branch of the engineering profession of which Mr. Preece was the most distinguished ornament) were being used for the service of man, and used for the development of the great industry of which they were proud to be members.

Lord LISTER, in acknowledging the toast, said Sir Henry Brackenbury had referred to Sir William Roberts-Austen's contributions to the applications of science to this great industry; but if any one wanted an example of what metallurgy owed to science and science to metallurgy, he could not take a better illustration than the President's remarkable investigations into the diffusion of one solid metal into another. These investigations had brought out results simply astonishing to the scientific world, altering their conception of the relations to each other of the different forms of matter, and whose practical applications they could only at present guess at. Such being the case, the Royal Society, which concerned herself with every department of science, felt the closest sympathy with their great practical Institute, and it had given him peculiar pleasure, and he felt it a peculiar honour, to have been asked to be present at their annual festal gathering.

Mr. W. H. PREECE, C.B., F.R.S. (President of the Institution of Civil Engineers), also replied. He said he felt extremely gratified at finding himself in the position as President of the Institution of Civil Engineers to say how pleased they always were to shower their hospitality upon those "Kindred Societies" who came and asked them for shelter in their building. Of all these societies there was not one that they welcomed with greater pleasure than the Iron and Steel Institute. The profession which their Institution embraced was probably the most ancient. He craved the pardon of the Lord Bishop of Rochester if, in supporting his argument, he was forced to bring into evidence some historical facts of the Book of which his Lordship was such a noble exponent. It was a great authority of the Iron and Steel Institute

who told them only two or three weeks ago that the inventor of wireless telegraphy was Eve. Eve in showering her smiles on Adam exercised for the first time the art of wireless telegraphy. He maintained also that it was the most learned. The only fact connected with the application of science to any useful purpose which occurred before the Flood showed that the Roberts-Austen of that period, a certain Mr. Tubal Cain, was an instructor of every artificer in brass and iron. He also referred to that great Book to point out to them that invention commenced at a very early period, and he hoped his Lordship would not be shocked when he asserted that the first and greatest inventor was Mr. Job. It was asserted that Job was asked if he could bring down the lightnings from heaven, that they might go and say unto them, "Here we are." Mr. Job did it, or it must be assumed that he did it; and if he did it, he must have known of the identity of lightning and electricity, which was only discovered by us in the last century. And more than that, if Job could bring the lightnings down from heaven and say unto them, "Here we are," he could only have said so with a telephone. Hence Job invented the telephone. We electricians were very proud of Job, for he was one of "Uz." Then, again, if any of them wished to know who was the great naval constructor of that period, they had to take the last chapter but one of Job, and there they would find a bold description of an ironclad, equal to that which could be produced by his friend Sir William Henry White. They of the present day were proud to see how science and practice were walking arm in arm down the corridor of Time. They had an illustration of this even before them that night, for while on the one part they had in their President science and industry linked together, they had in his case, in the Institution of Civil Engineers, practice assisted by science. Engineering was not a profession confined to one branch. It was generally imagined that by the title Civil Engineer their Institution looked only to roads, rails, and bridges, but the term Civil Engineer was originally introduced to distinguish their branch of the profession from military engineering. They as members of the Institution of Civil Engineers asserted that they brought under their ægis every branch of engineering. The profession of the engineer was that profession which applied the waste forces of nature and the great principle of energy to the wants, the happiness, and the comfort of mankind. The first note of science in that Book to which he referred was the appearance of the rainbow, and it was only now, at the present day, that they found his neighbour, Sir Norman Lockyer, applying his observations to develop still further this freak of nature which man

had not yet thoroughly unravelled. They hoped to see science and practice dancing a good old British country-dance hand in hand, showering on each side peace and plenty and health; but there was one thing they did hope—some of them here, at any rate—that one of the greatest advances that science could bring about would be a cessation of that barbarous practice which forced hosts to toast their guests, and to compel them to pay the miserable penalty of making a speech.

The toast of "Our Guests" was next proposed by Mr. EDWARD P. MARTIN (Retiring President). He said a glance at the printed list would show that they had among them many of the most eminent men of the day. They had already had the pleasure of listening to Lord Welby, who worked so long in the Civil Service for his country's good, and also of listening to Lord Lister, the high-priest of science, and the president of the greatest scientific society in the world. Then they had heard Sir Henry Brackenbury, the gallant general who was responsible for the most important factor in modern warfare, the Ordnance; and they had also their friend Sir William White, who was responsible for the designs of our warships and the reconstruction of the navy. Among the guests whom they had not had the pleasure of listening to were men of eminence in various fields. They had among them the Bishop of Rochester, an eminent representative of the Church, Sir Charles Fremantle and other representatives of the State, whilst their Colonies were well represented by Lord Strathcona and Mount Royal, the High Commissioner of Canada. Of the presidents of kindred societies there was a brilliant array. It had often been their good fortune to be guests both at home and abroad. This led him to remind them of their visit to Cardiff, where they enjoyed the hospitality of the Marquis of Bute, Lord Wimborne, Lord Windsor, and Sir William Lewis; and also the royal reception they received at the hands of the King of Sweden at Stockholm. They were all glad to hear that King Oscar was restored to health and strength after suffering a very serious illness. They had not forgotten the lavish hospitality of the Swedish people on that occasion. His Majesty King Oscar was represented that evening by His Excellency the Swedish and Norwegian Minister, with whose name, and with that of Sir Howard Vincent, he coupled the toast.

In response, His Excellency the SWEDISH AND NORWEGIAN MINISTER thanked Mr. Martin and Sir James Kitson for the kind words used in reference to the visit of the Institute to Sweden. His countrymen were at first a little uncertain what they could find to show to such

visitors as the members of the Iron and Steel Institute, but they soon found that the visitors took an interest in everything. This kind disposition encouraged them to do all that they could, and the result was such as they knew. They had written in their report that they liked the country; and for his own part he begged to add that the country liked the visitors.

Sir HOWARD VINCENT, M.P., also responded.

In proposing "Prosperity to the Iron and Steel Institute" the Right Honourable LORD STRATHCONA AND MOUNT ROYAL, G.C.M.G., said he was very happy indeed to have the opportunity and privilege of proposing it. It was one which required no words on his part to commend it; and he expressed the hope that by the aid of iron and steel the empire would be more closely knit together. But his pleasure in being present that evening was that he had the privilege of coupling with the toast the name of one for whom he had the very highest respect—the President of the Institute. He had known the President from his infancy, and not only himself, but his father and grandfather, who were respected by all who knew them.

The PRESIDENT, in responding, said he need not tell them how much touched he was by the way in which his oldest friend, Lord Strathcona, had proposed the toast. His Excellency had said it was by iron and steel that they must hope to knit the Empire together, and for his own part he must say that there was no portion of Her Majesty's dominion that he loved more or to which he would give anything he had than to Canada, which Lord Strathcona so worthily represented. They had listened to him for an hour that morning, and he did not intend to inflict another address upon them. It came to this: they, the members of the Institute, had done all the work of the nation in iron and steel, and they had been pleased to put him in a position which enabled him to sum up the result and place it before his fellow-countrymen. He was very proud of that position, and while he held it he would do his utmost to serve them to the best of his ability.

The proceedings then terminated.

THE JUBILEE OF THE AUSTRIAN SOCIETY OF ENGINEERS.

At their meeting on February 24, 1899, the Council of the Iron and Steel Institute resolved to present, on the occasion of the Jubilee of the Austrian Society of Engineers, a congratulatory address from the Institute, in which reference was made to the hospitality accorded by the Austrian Society on the occasion of the Institute's memorable visit to Vienna in 1882. The Secretary, who was instructed to represent the Institute, submitted to the Council the following report on the proceedings:—

The General Meeting to celebrate the Jubilee of the Austrian Society of Engineers took place in the Council Chamber of the Vienna Town Hall on Saturday, March 18, 1899. There was a large attendance of members, and representatives of sixty-eight kindred Societies were present. After an address of welcome from the President, Mr. Franz Berger, a congratulatory address was delivered by Count Kielmansegg, the Governor of Lower Austria, in the course of which he announced that H.M. the Emperor had conferred on the Society the great Gold Medal in recognition of the value of its work. Addresses were also delivered by the Ritter von Wittek, Minister of Railways, and by Baron von Gudenus, Marshal of Lower Austria. The delegates with illuminated addresses from kindred societies were then presented to the President by Professor J. Klaudy, the chairman of the executive committee. The first address received was that from the Iron and Steel Institute, which was handed to the President with a congratulatory speech by the Secretary of the Institute. He was followed by Mr. A. Jacquin, representing the French Society of Engineers; by Mr. Stübben, representing the German Architects and Engineers' Societies; by Professor Ulbricht, representing the Saxon Engineering Society; by Mr. Peters, representing the Society of German Engineers; by Mr. C. von Hieronymi, representing the Hungarian Engineers' Society; and by representatives of various Austrian Societies and Corporations. An address from the Society of German Ironmasters was received after the meeting was closed.

A paper was then read by Mr. Anton Rücker, Government mining engineer, on the progress made during the past fifty years. In the evening a banquet was held, at which a large number of members and delegates were present, and the next day was devoted to visiting engineering works in the neighbourhood.

Previous to the Jubilee meeting, papers had been communicated to the various sections of the Society, describing the development of the technical sciences and arts during the last fifty years. Building construction was dealt with by Mr. Franz von Neumann; mechanical engineering by Mr. P. Zwiauer; mining and metallurgy by Mr. E. Heyrowsky; railway engineering by Mr. Wilhelm Ast; sanitation by Mr. Attilio Rella, and technical electro-chemistry by Mr. Victor Engelhardt. All these papers have been published in the *Zeitschrift* of the Society.

In reviewing the progress of the mining and metallurgical industries in Austria from 1848 to 1898, Mr. E. Heyrowsky remarked that Austrian mining dated from prehistoric times. The Noric iron from Styria, Carinthia, and Carniola was known to the Romans, and constituted an important article of export to the southern provinces of the empire, where it was made into arms and tools. Mining for the precious metals—for example, for gold in the Salzburg Alps, and for silver at Kuttenberg, at Iglau, and at Joachimsthal, where in 1518 the first dollar (*Thaler*) was minted—also dates back to prehistoric times. Fifty years ago, all the blast-furnaces used charcoal as fuel, with the single exception of the Wittkowitz works, then belonging to Baron von Rothschild, which as long ago as 1831 possessed one coke blast-furnace. The production of these charcoal furnaces was very small, not more than 1 to 10 tons in twenty-four hours. Cold blast was used, and the copper tuyeres were not kept cool. The pig iron was treated in small finery hearths with charcoal; the yearly out-turn of a hearth of this kind did not exceed 100 to 200 tons. The iron was worked with tilt-hammers driven by water-wheels, and at only a very few works were there puddling furnaces, welding furnaces, or steam rolling-mills.

The production of pig iron in Austria was as follows in the years named :—

| Year. | Tons. |
|----------------|---------|
| 1848 | 155,788 |
| 1858 | 244,677 |
| 1868 | 262,630 |
| 1878 | 293,195 |
| 1888 | 586,121 |
| 1897 | 887,944 |

The total production of pig iron in Austria fifty years ago was only 155,738 tons. This amount was obtained from 132 blast-furnaces. Consequently the out-turn per blast-furnace averaged 1200 tons. Strenuous attempts were then made to concentrate the working, to increase the out-turn of the furnaces, and to improve the whole manufacture. The waste gases of the furnaces were collected and utilised for heating the blast, for roasting the ore, and for heating steam-boilers; water-jacketed tuyeres were employed, the boshes were cooled, and mechanical hoists adopted. The finery hearths were discarded and replaced by single and double puddling furnaces and welding furnaces; steel puddling was introduced, and rails were made either with puddled steel heads or entirely of puddled steel of excellent quality; the manufacture of cement steel was introduced, and that of cast steel greatly extended. Difficulties in the use of poor coal, rich in moisture and ash, were overcome by methods of gas-firing. Directly after Bessemer's discovery had been applied in England and in Sweden, it was adopted by Austria. On November 23, 1863, the first Bessemer charge was blown at Prince Schwarzenberg's works at Turrach, in Styria. This was owing to the initiative of the great metallurgist, the Ritter Peter von Tunner, Bessemer Gold Medalist of the Iron and Steel Institute, who died in 1897 at the age of eighty-eight. The Turrach works were soon followed, also at Tunner's suggestion, by the Bessemer works at Hoft, in Carinthia (1864), and in the same year by the Bessemer works at Neuberg, and soon afterwards Bessemer plants were erected at Ternitz, Teplitz, Graz, Zeltweg, Wittkowitz, Kladno, Prevali, and Trienietz.

With the introduction of the Bessemer process, Austria entered upon a new era of increased outputs and reduced costs. Consequently, in 1867 and 1868 the Government sold all its ironworks. Joint-stock companies were formed, and new branches of manufacture were adopted. In the third decade of the fifty years under review new blast-furnaces were built at Schwechat and Judenburg in Styria, and at Liebschitz and Rokitzan in Bohemia; rolling-mills were started at Köflach, Wasendorf, Unzmarkt, and St. Michael in Styria; and steelworks and wire-mills at Graz.

The mean out-turn was increased to 4650 tons per year per furnace, and extensive use was made of the Siemens regenerative system. The production of Bessemer metal, beginning in the year 1863 with 21 tons, reached 70,000 tons in 1873, and 100,000 tons in 1878. The last two decades of the period under consideration presented a remark-

able development in the Austrian iron industry. This was due to the fact that the basic process rendered it possible to utilise phosphoric iron ores. This process was first put in practice by Thomas and Gilchrist in 1878, and in the next year (1879) the first charge was blown by this process at Kladno, in Bohemia. In the same year the Teplitz works and the Wittkowitz works also adopted the basic process. In this year the latter works passed from the possession of Baron von Rothschild into that of the Wittkowitz Mining and Iron Works Company, and were converted by the skill of Mr. Paul Kupelwieser and the Ritter Max von Guttman, two members of the Austrian Society of Engineers and of the Iron and Steel Institute, into one of the greatest iron-works in Austria. The basic process was soon adapted to the open-hearth process, and came into use in Bohemia, where it rendered possible the utilisation of the phosphoric ores of the Nucvizer mines. By the powerful initiative of Mr. Carl Wittgenstein, member of the Austrian Society of Engineers and of the Iron and Steel Institute, the Kladno plant was adapted to the new process and considerably enlarged, the Fürstenberg iron-works (now the Bohemian Mining Company) coming into the new combination. Under his powerful hand entirely new works arose, such as the Carl Emil works and the blast-furnace plant at Königshof, near Beraun, the sheet-rolling mills of the Rudolf works at Teplitz, and quite recently (1890) the cast-steel works, the Poldi works at Kladno.

In 1888 the Wittkowitz works started making armour-plates, which proved very satisfactory. About the same time another new branch of industry was started in Austria, namely, the manufacture of wrought iron tubes at Wittkowitz and at the Haltschinsky works, Schönbrunn, near Moravian Ostrau. In 1892 the railway from Leoben to Eisenerz was completed, and the supply of excellent iron ore thus rendered available led to the building in 1896 at Donawitz of a large coke blast-furnace, which has now the greatest daily out-turn of pig iron, 240 tons in twenty-four hours, in Austria. As a new creation of quite recent date the blast-furnace plant at Servola, near Trieste, may be mentioned. It is built after the American style, and was blown in on November 24, 1897. English coke and Spanish, African, Greek, and Bosnian iron ores are used.

It is thus evident that the iron industry of Austria has made considerable advances. Whereas in the fifties a blast-furnace with a daily out-turn of 20 tons, and in the seventies one with a daily out-turn of 50 to 60 tons were about the largest, at the present time there are

blast-furnaces which produce daily 160 tons (Kladno), 180 tons (Wittkowitz), 220 tons (Königshof), and 240 tons (Donawitz and Servola) of pig iron, and a new furnace is projected at Eisenerz with a daily output of 400 tons. The production of mineral fuel has increased in a remarkable manner during the period under review. The output of coal in Austria in 1848 was 716,412 tons; in 1897 it was 10,492,770 tons. The output of brown coal in 1848 was 409,521 tons; in 1897 it was 20,458,092 tons.

The Memorial volume issued in commemoration of the Jubilee, a copy of which has been presented by the Austrian Society to the Iron and Steel Institute Library, is worthy of the occasion. It covers 154 pages, is admirably illustrated by Baron Franz von Krauss, and contains portraits of past presidents, and excellent sketches of works with which members of the Society have been connected. Mr. Carl Stoeckl's history of the Society is most ably written.

The Society dates from 1848, the year of the revolution. It was, we read, political discontent and dissatisfaction with the status of the engineer, who in public and social life was merely the technical assistant of his administrative superior, that brought Friedrich Schnirch and his friends, all engineers, to a preliminary meeting in the inn "Zum Engländer" on May 2, 1848. The meeting took place in Vienna, which has always been the seat of the Society. The Government sanction followed within a few weeks, and the Government granted the new Society hospitality. The Society counted seventy-nine corporate and two corresponding members. The statutes distinguished between corporate, associate, and corresponding members; the second class of membership was afterwards abolished. Austria had few private industries then, and only 800 miles of railway. For some time accessions to the new body were sparse, although the annual subscription, originally fixed at 16 florins, was reduced to 12 florins. The Journal of the Society had been started with the year 1849 at the personal risk of the first president, Adalbert von Schmid.

One of the first questions which the Society submitted to a committee, the Semmering Pass Railway, was discussed with great warmth in October 1849. The committee insisted upon the necessity of wire-rope traction. Carl von Ghega, who finally carried his point, advocated special mountain-line locomotives. An international locomotive competition was invited. Maffei, of Munich, obtained the first prize of 20,000 ducats with his engine "Bavaria"; John Cockerill the second with the "Seraing"; while the Vienna-Gloggnitz Railway Works and

W. Günther of Vienna secured the third and fourth prizes. None of these engines, however, gave complete satisfaction; but Wilhelm von Engerth, later several times president of the Society, who had supported Ghega from the first, constructed the real "Semmering Pass" locomotive, and Ghega was able to open the line to traffic in July 1854. When Lesseps' Suez Canal scheme was discussed in 1857, Negrelli produced a paper of his of ten years previous, in which he had proved that the cutting would only bring the sea back to parts which it had once occupied. The stagnation in railway enterprise kept the number of members down to 559 in 1860. Yet prizes were offered for essays on roof construction and on lubrication in railway service. There were also discussions on bridge-building materials. The Austrian iron was poor, rolling-mills were wanting, and Schnirch's link suspension bridge over the Danube Canal at Vienna was dimensioned according to tests conducted with faulty apparatus. Risky structures were built in spite of all warnings, until the bridge over the Pruth, near Czernowitz, broke down under a goods train. The bridge was simply not strong enough, and lacked proper connection between the cast iron stays and the forged iron ties.* The Society afterwards amply made amends for the mistakes of some of its members in this field.

In 1864 the Austrian architects joined the Society, which, up to that time, had been a body devoted to surveying, road and railway construction, water supply, mining and metallurgy. Henceforth every great undertaking in Austria, every great question affecting the profession, such as the training and status of engineers and architects, technical education, patent laws, and workmen's insurance, came before the Society. The city of Vienna had a sufficient number of momentous problems to solve—the water supply, Danube regularisation, rebuilding of the old town, and intra-urban traffic. In all these questions the Society took a prominent part, and their committees rendered valuable aid to science. Thus, when Humphrey and Abbot published their views on the flow of water in rivers, the Society could point to careful observations on the Schwarza river, near Vienna, which entirely supported these theories.

By 1866 a railway-building fever had developed which the wars of that year checked. Over the Arlberg Tunnel scheme the Society divided into two camps. The minority, backed by influential officials, maintained that a single-track tunnel, 4·5 miles in length, would be preferable to a double-track tunnel 7 miles long, to be cut at a lower level. But Franz von

* *Engineering*, vol. lxvii. p. 713.

Rziha, an authority on tunnel construction, prevailed with his exposition of the difficulties of building a single-track tunnel, and of keeping such a tunnel well ventilated and in good repair. Cement and cement-testing were first brought before the Society by Winterhalder in 1863, when it was established that Austria need not go abroad for her supply of cement. A Cement Committee was nominated in 1877. In 1890 another committee was charged with a series of comparative tests on the strength of arches. It had become customary to embed iron wires or bars in concrete, but the public had little confidence in the strength of "armoured or unarmoured" concretes, terms which have passed into general use on the Continent. The experiments were conducted on a large scale at Purkersdorf and at other places, and extended over several years. They were generally favourable both to stone and concrete arches. The Jaremcze railway bridge over the Pruth in Galicia, with a span of 213 feet, is one of the indirect outcomes of this investigation.

Great credit is also due to the Society for removing the suspicion which rested on basic steel. It was thought to be inferior to Bessemer and open-hearth steel, and not a safe material for bridge-building. The Bohemian ironmasters, who produced chiefly basic steel, were greatly exercised in the matter, and they were more than pleased when the Research Committee proved in 1889 and the following years that the alleged inferiority did not exist. Of other questions which the Society has taken up, mention may be made of locomotive boilers, girder-beam types, iron classification, regularisation of the Lower Danube between Moldawa and the Iron Gates, ship-lifting machinery, canals, &c.

In March 1898 the Society numbered 2377 members and eleven corresponding members. The six sections of the Society are now: (1) architecture; (2) roads, bridges, and railways; (3) mechanical engineering; (4) sanitary engineering; (5) mining and metallurgy; (6) chemistry. Originally the sections met weekly or fortnightly; since 1860 the Society has held monthly meetings. An interesting feature of their constitution is the board of arbitrators, created in 1857 to intervene in cases of dispute between members and between members and officers of the Society. In 1884 the Society adopted a permanent badge for use on excursions; it shows the bust of Galileo, his words, "*E pur si muove*," and the name of the Society. The president and officers were first elected for the period of one year, and were eligible for re-election; the period was afterwards extended to two years. The Society has been most fortunate in the choice of its presidents. Thus

it is that the list is not long, several of them having been re-elected again and again. Adalbert von Schmid occupied the chair from 1848 to 1856; Wilhelm von Engerth from 1860 to 1863, 1868 to 1870, 1872 to 1874; Friedrich Schmidt, the great architect, from 1866 to 1868, 1870 to 1872, 1874 to 1877, 1879 to 1881, and 1883 to 1885. The president during the Jubilee, Franz Berger, had occupied the chair twice before. The other presidents are in chronological order: L. von Foerster, Peter von Rittinger, the celebrated mining engineer, Karl Pfaff, Karl Prenninger, Karl Bischoff, Leopold von Hauffe, Franz von Gruber, and Johann von Radinger.

OBITUARY.

HARRY ALLEN died at Sheffield on February 23, 1899, in his forty-fifth year. He was a nephew of Sir Henry Bessemer, and was chairman of Henry Bessemer & Company, Limited, Sheffield. For a number of years he was a member of the Cutlers' Company of Sheffield, and at the time of his death occupied the position of Senior Warden of that ancient corporation. He was an enthusiastic Freemason, and had held the office of Provincial Senior Grand Warden. He was elected a member of the Iron and Steel Institute in 1884.

WILLIAM EVANS, one of the veterans of the British iron trade, died at his residence, Ilkley, Yorkshire, in May 1899. He was selected over thirty years ago to undertake the management of the celebrated works of Bowling, Yorkshire, which, with the Low Moor Works, Bradford, the Farnley, and the Monkbridge Works, was distinguished for the manufacture of the best Yorkshire iron, and also carried on, to a limited extent, the manufacture of crucible steel. He retired from the Bowling Works some twelve years ago. He was an original member of the Iron and Steel Institute, and was elected Member of Council in 1880, and Vice-President in 1883.

REUBEN FARLEY died on March 11, 1899, at his residence at West Bromwich. Born in 1826, he began his business career as a colliery proprietor in 1847. In 1861, in conjunction with his brother-in-law, Mr. George Taylor, he purchased the Summit Foundry. He was chairman of Fellows, Morton, & Clayton, Limited, the canal-carriers, of Edwin Danks, Limited, boiler manufacturers, of Oldbury, and of the Hamstead Colliery Company. He had a considerable interest in the Sandwell Park Colliery Company, and took an active part in promoting that enterprise. He was a member of the West Bromwich Improvement Commissioners, and one of the leading members of the Corporation. He was a county magistrate for Staffordshire for nearly thirty years, and a Justice of the Peace for the borough of West Bromwich. He

took great interest in all local affairs, and was a munificent benefactor to West Bromwich, his numerous gifts including Farley Park, a bandstand, kiosk and fountain in Dartmouth Park, a drinking fountain in the town of West Bromwich, and the Oak House Museum and pleasure-grounds. He was an original member of the Iron and Steel Institute.

SIR DOUGLAS GALTON, K.C.B., died on March 10, 1899, at his town residence. Born in 1822, he had a brilliant career at the Royal Military Academy, and obtained his commission in the Royal Engineers in 1840. In 1847 he became Secretary to the Railway Commission, and soon afterwards Inspector of Railways and Secretary of the Railway Department of the Board of Trade. His services in connection with railways obtained for him the distinction of being elected an honorary member of the Institution of Civil Engineers. In 1860 he became Assistant Inspector-General of Fortifications, and two years later Assistant Under-Secretary for War. From 1870 to 1875 he was Director of Public Works in the office of H.M. Board of Works. For twenty-five years he acted as General Secretary of the British Association, an office which he resigned in 1895 to become President. He was elected a Fellow of the Royal Society in 1863. He was an energetic member of many other scientific societies, notably of the Society of Arts, of which he was chairman in 1886. He was a D.C.L. of Oxford and an LL.D. of Durham and Montreal. He was made a C.B. in 1865, and promoted to K.C.B. in 1887. To the general public he was best known as an authority on sanitary questions. In addition to administrative and professional work, he took great interest in the social functions of the various scientific bodies with which he was associated. He was the oldest member of the Geological Society Club, having been elected in 1850. Although a soldier, his career was almost entirely a civil one. Indeed, he never attained a higher rank in the army than that of captain. He was elected a member of the Iron and Steel Institute in 1882.

WILLIAM HANSON died at Middlesbrough on May 6, 1899. Born at Staindrop in 1837, he was educated at York, and began his business career in the colliery offices of Messrs. J. & J. W. Pease at Darlington. He remained there until 1864, when he was intrusted with the business management of Messrs. B. Samuelson & Company's Newport ironworks at Middlesbrough, which had just been established. He was taken into partnership in 1872, and in 1887, when the concern was

converted into a private limited liability company, he was appointed managing director. He was also a director of the North Brancepeth Colliery Company, of Messrs. Sadler & Company, Limited, Chemical works, Middlesbrough, and of the Bishopley Limestone Quarries Company. He was also connected with shipping. He was chairman of the Graving Dock Committee, and for many years represented the payers of dues on the Tees Conservancy Commission. He was president of the Cleveland Club, and was held in great esteem by all classes in Middlesbrough. He was an original member of the Iron and Steel Institute.

JEREMIAH HEAD died at St. Leonards on March 10, 1899. Born in 1835, he was educated at the well-known school of the Society of Friends at Tulketh Hall in Lancashire. In 1851 he was articled to the late Robert Stephenson of Newcastle-upon-Tyne, who selected him in 1857 as resident engineer in the construction of the iron bridge over the Wear at Sunderland. His attention was subsequently devoted to improving the steam-plough with conspicuous success. In 1863, in conjunction with Mr. Theodore Fox and others, he established the Newport Rolling-Mills at Middlesbrough, and from 1867 to 1874 these works were carried on on the industrial copartnership principle. In 1885 the works were stopped, and since that date Mr. Head followed the profession of a consulting engineer. He was the originator, in 1865, of the Cleveland Institution of Engineers, of which he acted as secretary until 1871, when he became president. In 1885 he was president of the Institution of Mechanical Engineers, and in 1893 was president of the Mechanical Science Section of the British Association. He was also one of the most prominent members of the Board of Conciliation and Arbitration for the Manufactured Iron Trade of the North of England, and acted as one of the treasurers up to the time of his death. As a man of science and as an inventor he accomplished much. He undoubtedly made his influence felt, both industrially and socially, especially at Middlesbrough, where the Cleveland manufactured iron trade, of which he was one of the pioneers, owes him more than can easily be estimated. He has enriched technical literature with a large number of contributions of permanent value. His last paper was communicated to the Institution of Civil Engineers very shortly before his death. It dealt with the Lake Superior iron ore region and its influence on the production of iron and steel, a question which he, in conjunction with his son and partner, Mr. A. P. Head, had specially

investigated on the spot. He was one of the original members of the Iron and Steel Institute, and was a regular attendant at its meetings. He contributed to the *Proceedings* papers in 1871 on the efficiency of plain cylindrical boilers; in 1872 on the Newport puddling furnace; in 1873 on a new method of preventing shock in reversing rolling-mills; another in 1873 on the recent boiler explosion at the Linthorpe Iron-works; in 1894 on Scandinavia as a source of iron ore supply; in 1896 on the manganese ore deposits of Northern Spain, and in 1897 on charging open-hearth furnaces by machinery.

ALFRED EPHRAIM HUNT died at Philadelphia, Pennsylvania, on April 26, 1899. Born at East Douglas, Massachusetts, in 1855, he was one of the most prominent metallurgical engineers of America, and the leading authority on the aluminium industry. The immediate cause of Captain Hunt's death was hæmorrhage, complicated with weakness of the heart; but these were only indirect causes, which were themselves the result of a fever contracted while he was in command of Battery B of Pittsburgh at Chickamauga Park, and later in the Porto Rico campaign of the Spanish-American war. He was a descendant of William Hunt, who went from England to Concord, Massachusetts, in 1635. He was educated at the Roxburgh High School and the Massachusetts Institute of Technology, graduating from the latter institution in metallurgy and mining engineering in 1876. For some time after his graduation he was with the United States Geological Survey, and later became connected with the Bay State Ironworks in South Boston, where the second open-hearth furnace in America was set up under his direction. For this Company he also went to Michigan to explore for iron ore, and upon the samples brought back by him the first report was made on the Michigamme mines, the first of the famed ore discoveries in Northern Michigan. From 1877 to 1879 he was manager and chemist of the open-hearth steelworks at Nashua. He then went to Pittsburgh as superintendent and chemist with Park Brothers & Company, but in 1882 he resigned, and, with George H. Clapp, of the same firm, formed the well-known firm of Hunt & Clapp, and established a chemical laboratory, and did the chemical work of the Pittsburgh Testing Laboratory. It was while he was in active management of this laboratory that he became interested in Charles M. Hall's process for the reduction of aluminium, which he, in company with the inventor, finally developed into the important works of the Pittsburgh Reduction Company. His education and intimate knowledge of

chemistry made him at once recognise the merit of the scientific principles involved in the process, and as soon as he had familiarised himself with its details, he set about organising the Pittsburgh Reduction Company, raising the capital among his personal friends in Pittsburgh. At the time that he and his associates began the manufacture of aluminium by the Hall process, that metal was selling at fifteen dollars per pound. At his death it was selling at from thirty to forty cents. per pound. The manufacture of aluminium was only one of the important enterprises of Captain Hunt's work as an engineer. The others were the opening of the Michigan iron mines, the adoption of the open-hearth process in steel manufacture, and the development of the commercial testing laboratory from its first small beginning to a business and engineering position of recognised standing and merit. He was a member of most of the leading American technical societies, and contributed largely to technical literature. For the merit of a paper written for the International Engineering Congress, held in Chicago in 1893, he was awarded the Norman Gold Medal by the American Society of Civil Engineers. He was elected a member of the Iron and Steel Institute in 1888; in 1890 contributed to its *Proceedings* a paper on the inspection of materials of construction in the United States. He was an energetic member of the Central Committee that organised the visit of the Institute to America in 1890.

ROBERT HUTTON died on January 25, 1899. He was connected with the Batts Foundry at Whitby. He was elected a member of the Iron and Steel Institute in 1876.

JOHN JACKSON, of Stubben Edge, Chesterfield, died at Falmouth on February 28, 1899, at the age of fifty-five. He was the principal partner in the Clay Cross Coal and Iron Company, and was one of the leading men in the Midland coalfield. He was regarded as a model employer of labour; and in the Coal War of 1893 he was one of the coal-owners who sat at the round-table conference at the Foreign Office. He was a Justice of the Peace for Derbyshire, a member of the Institution of Civil Engineers, and for some time president of the Chesterfield Institute of Mining Engineers. He was elected a member of the Iron and Steel Institute in 1881.

ADOLF JOST died on October 23, 1898, at his residence in Sheffield, at the age of thirty-eight. Son of the late Jacob Jost, of Frankfurt-on-

the-Main, he was manager of the Attercliffe Steelworks, Sheffield. He was elected a member of the Iron and Steel Institute in 1894.

STEPHEN LANCELOT KOE died on May 5, 1899, at his residence in Brighton in his seventy-second year. Born in London on May 18, 1827, he was the son of the late H. B. Koe, Q.C. In 1844 he was apprenticed to Mr. Thomas Paley at the Bowling Ironworks. He was subsequently engaged in the locomotive works of Messrs. E. B. Wilson & Co. of Leeds, and from 1849 to 1851 as assistant to the inspector of permanent way on the Great Western Railway at Bath. In 1852 he was articled to a civil engineer, Mr. W. H. Sankey, to whom he acted as assistant on various railway works on the Continent. In 1857 he was engaged as assistant engineer on the Madras Railway. In 1863 he returned to England and was appointed manager of the Bowling Iron Company. Two years later his sight began to fail, and in 1870 he resigned the managership in consequence of this failure. He was elected a member of the Iron and Steel Institute in 1870.

JOSHUA LANCASTER died in March 1899. He was identified with his brother, the late Mr. John Lancaster, Vice-President of the Iron and Steel Institute, in the control of the extensive works of Earl Granville in North Staffordshire. In 1865 he became the first chairman of the Wigan Coal and Iron Company. A few years later he severed his connection with this company, and became part owner of the ironworks at Darwen and at Mostyn. He was elected a member of the Iron and Steel Institute in 1874.

JOHN WILLIAM NAYLOR, managing director of the firm of Fairbairn, Naylor, Macpherson & Co., of Leeds, died suddenly in London on June 4, 1899, in his seventy-second year. His early associations with the great engineering works of which he subsequently became the practical head were of a most modest character. As a raw lad he went to work for the celebrated Peter Fairbairn, who, marking his diligence, helped him to grow with the business. In 1863, two years after Sir Peter Fairbairn's death, Sir Andrew Fairbairn took him into partnership. In the twenty years that had elapsed since his entry into the works, he had passed with credit through all grades. In 1883 the style of the firm was altered, but he remained a director. He also acted as director of the Lancashire and Yorkshire Railway Company, and held the office of chairman of the Income-tax Commissioners in the Leeds district.

He was a justice of the peace for the city of Leeds as well as for the West Riding, and was a munificent contributor to the building of a new church at Chapel Allerton, where he lived. He was a member of the Institution of Mechanical Engineers, and was elected a member of the Iron and Steel Institute in 1889.

ERNEST WHEATCROFT died in June 1889 at the age of forty. He went to Sheffield as a lad, and entered the laboratory of John Brown & Co., where he remained as chemist for a number of years. About seventeen years ago he entered Hadfield's Steel Foundry as a chemist, and eventually became manager of one of the departments. He was elected a member of the Iron and Steel Institute in 1892.

RICHARD OGLE died in Manchester on January 2, 1899, in his seventy-fifth year. He was one of the oldest representatives of the iron trade in Lancashire, having been connected with the firm of Richard Ogle & Company for upwards of forty years. He was also largely interested in the Lincolnshire blast-furnace. Since 1865 he had represented the North Lincolnshire Iron Company, and for several years occupied the post of chairman of the board of directors. He was elected a member of the Iron and Steel Institute in 1875.

FREDERICK RYLAND died on February 11, at his residence, Baskerville House, Court Oak Road, Harborne, Birmingham, at the age of fifty-four years. He was apprenticed to Messrs. May & Mountain, and on completing his term he went to Messrs. Archibald Kenrick & Company, Limited, of West Bromwich, where he remained throughout the rest of his life. On the company being converted into a limited liability undertaking he became a director, and later on shared the managing directorship with Mr. G. Kenrick. He took a prominent part in educational and charitable work. He was one of the founders of the West Bromwich Institute. He also took much interest in the school of art and design in connection with the Institute. He was elected a member of the Iron and Steel Institute in 1890.

J. MANN THOMSON, of Dankeith, Ayrshire, died suddenly at Mentone on March 12, 1899, at the age of sixty-three. He had acted as chairman of the firm of William Dixon, Limited, of Glasgow, since the business was turned into a private limited company in 1872, and was well known in the iron and coal trades. He was an original member of the Iron and Steel Institute.

FREDRIC ELIAS WARBURG died on February 9, 1899. He was born in Gothenburg, Sweden, on June 18, 1832. To him in a great measure is due the development and success of the Grängesberg iron mines, on the output of which the German blast-furnaces are largely dependent at the present day. He was a director of the Swedish Central Railway, one of the three lines for transporting the Grängesberg ore to the coast, and brought this Company from a state of bankruptcy to one of affluence, besides taking a leading part in the reorganisation of several other Swedish railways. He formerly held a considerable interest in the Darwen & Mostyn Iron Company, and his co-operation had more than once been sought on the Board of one of the largest West Coal Steelworks. Besides being a director of several prosperous manufacturing concerns in Sweden, Germany, and Russia, he was director of the Electric Traction Company, now building the electric underground line for the Central Railway Company. Possessed of a world-wide experience, especially in commercial and financial matters, his advice was sought and followed on every side. He was elected a member of the Iron and Steel Institute in 1890.

NICHOLAS WILLIAMS died at his residence at Millom on February 11, 1899, at the age of fifty-nine. Son of the late Daniel Williams of Rhymney, Monmouth, he had been for twenty-eight years engineer to the Hodbarrow Mining Company. He was elected a member of the Iron and Steel Institute in 1872.

ROBERT YOUNG died on January 3, 1899. Born at Newcastle-on-Tyne on August 9, 1846, he was educated at the grammar-school in that town, and was apprenticed to the Haswell & Ryhope Colliery Company, Sunderland. He remained in the employment of that company for many years, and was subsequently appointed manager of the Castle Eden Colliery. For the last twenty years of his life he was in business in London as a railway-plant contractor. He was elected a member of the Iron and Steel Institute in 1886.

ADDITIONS TO THE LIBRARY

DURING THE FIRST HALF OF 1899.

| Title. | By whom Presented. |
|--|---------------------------------|
| "Tasmania and its Mineral Wealth." Special Edition of the <i>Australian Mining Standard</i> . July 1, 1898. Melbourne. 1898. | The Agent-General for Tasmania. |
| "The Progress of the Mineral Industry of Tasmania for the Quarters ending March 31, 1898, and June 30, 1898." Tasmania. 1898. | The Agent-General for Tasmania. |
| "Marine Boilers: their Construction and Working." By L. E. Bertin. Translated and Edited by Leslie S. Robertson. London. 1898. | The Publisher. |
| "The American and Foreign Iron Trade in 1897 and Immediately Preceding Years." By J. M. Swank. Washington. 1898. | The Author. |
| "Thirty-sixth Annual Report of Messrs. C. E. Müller & Co." January 11, 1899. Middlesbrough. | C. E. Müller. |
| "American Society of Mechanical Engineers. Annual Address of the President, C. W. Hunt." New York. 1898. (Pamphlet.) | The Author. |
| "Journal of the American Foundrymen's Association." Vol. v. No. 29. November 1898. | T. D. West. |
| "A Study of the Micro-Structure of Bronzes." By A. E. Outerbridge, Jun. Philadelphia. 1899. | The Author. |
| "Annual Report of the Chief of the Bureau of Steam Engineering." Washington. 1898. | The Department. |
| "Mild Steel. The Development of its Manufacture and Use." By James Riley. London. 1898. (Pamphlet.) | The Author. |

| Title. | By whom Presented. |
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| "The Production of Iron Ores in 1897." By John Birkinbine. Washington. 1898. (Pamphlet.) | The Author. |
| "The <i>Shipping World</i> Year Book for 1899." | The Editor. |
| "The London Directory for 1899." | The London Directory Co., Ltd. |
| "The English Directory and Gazetteer." London. 1898. | Wm. M'Donald & Co., Ltd. |
| "University Correspondence College Matriculation Directory." No. xxv. January 1899. London. 1899. | W. B. Clive. |
| "Journal of the American Foundrymen's Association." Vol. v. No. 30. December 1898. | T. D. West. |
| "Fifth Supplement to the Register of the British Corporation for the Survey and Registry of Shipping." Additions and Corrections. February 1899. | The Corporation. |
| "Manual of the Geology of India. Part I. Corundum." By T. H. Holland. Calcutta. 1898. | The Geological Survey of India. |
| "The Development of Modern Industry." By Henry Webb. Manchester. 1899. | The Author. |
| "List of the Federated Engineering and Ship-building Employers who Resisted the Demand for a Forty-eight Hours Working Week." Glasgow. 1898. | The Committee of the Federated Employers' Association. |
| "Henry Bessemer, 1813-1898." By James Dredge. Reprinted from the <i>Transactions of the American Society of Mechanical</i> | The Author. |
| "Mines and Quarries. General Report and Statistics for 1897. Part iv. Colonial and Foreign Statistics." Edited by C. le Neve Foster, D.Sc. London. 1899. | The Under-Secretary of State. |
| "Proceedings of the Engineers' Club of Philadelphia." Vol. xvi. No. 1. February 1899. | The Secretary. |
| "Relations between the Chemical Constitution and the Physical Character of Steel." By W. R. Webster. Philadelphia. 1898. (Pamphlet.) | The Author. |
| "The Relation of Tensile Strength to Composition in Structural Steel." By W. R. Webster. Philadelphia. 1898. (Pamphlet.) | The Author. |

| Title. | By whom Presented. |
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| "Specifications on Structural Steel and Rails." By W. R. Webster. Philadelphia. 1899. (Pamphlet.) | The Author. |
| "Standard Specifications for Steel." By W. R. Webster. New York. 1899. (Pamphlet.) | The Author. |
| "Reid's Railway Guide." Jubilee Edition. April 1899. Newcastle-on-Tyne. 1899. | The Publishers. |
| "Etat Actuel de la Siderurgie en Suède." By H. Ponthière. Brussels. 1899. (Pamphlet.) | The Author. |
| "Examen et Analyse des Combustibles Minéraux par les Rayons X." By M. Couriot. Paris. 1898. | The Author. |
| "Some Conditions of the American Iron and Steel Industries. A Comparison." By Walter Dixon. Glasgow. 1899. | The Author. |
| "Mines and Quarries. General Report and Statistics for 1898. Part I. District Statistics." London. 1899. | The Under-Secretary of State. |
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| "Papers read before the Engineering Society of the School of Practical Science, Toronto." No. 12. 1898-99. | The Society. |
| "Annual Reports of the Harbour Commissioners of Montreal for the Year 1898." Montreal. 1899. | The Commissioners. |
| "Mines and Quarries: Reports of Her Majesty's Inspector of Mines for the North Wales, &c., District (No. 9) to Her Majesty's Secretary of State for the Home Department for the Year 1898." London. 1899. | C. le Neve Foster. |
| "Report from the Special Committee on Secret Commissions to the Council of the London Chamber of Commerce." London. 1899. | The London Chamber of Commerce. |
| "Memorandum by the Chief Engineer of the Manchester Steam-Users Association." Presented at the Annual Meeting. May 2, 1899. Manchester. 1899. | The Association. |
| "The Petroleum Industry of Roumania." By D. A. Sutherland. London. 1899. Reprinted from the <i>Petroleum Review</i> . April 1 and 15, 1899. | The Editor of the <i>Petroleum Review</i> . |

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| "Historical Sketch of the First Institution of Mining Engineers." By Bennett H. Brough. London and Newcastle-upon-Tyne. 1899. (Pamphlet.) | The Author. |
| "Association Alsacienne des Propriétaires d'Appareils à Vapeur." Exercice 1898. Section Française. Nancy. 1899. | The Association. |
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INSTITUTIONS.

The Publications of the Institute are exchanged for those of the following Institutions :—

LONDON.

Board of Trade.
 British Fire Prevention Committee.
 Chemical Society.
 City and Guilds Institute.
 Geological Society.
 H.M. Patent Office.
 Imperial Institute.
 Institution of Civil Engineers.
 Institution of Electrical Engineers.
 Institution of Mechanical Engineers.
 Institution of Mining and Metallurgy.
 Institution of Naval Architects.
 Royal Artillery Institution.
 Royal Institute of British Architects.
 Royal Institution.
 Royal Society.
 Royal Statistical Society.
 Royal United Service Institution.
 Society of Arts.
 Society of Chemical Industry.
 Society of Engineers.
 University College.

PROVINCIAL.

Cleveland Institution of Engineers.
 Engineering Society (Leeds).
 Hull and District Institution of Engineers.
 Institution of Engineers and Shipbuilders in Scotland.
 Liverpool Engineering Society.
 Liverpool Polytechnic Society.
 Manchester Association of Engineers.
 Manchester Geological Society.
 Mason College (Birmingham).
 Merchant Venturer's Technical College (Bristol).
 Mining Institute of Scotland.
 North-East Coast Institution of Engineers.
 North of England Institute of Mining and Mechanical Engineers.
 Royal Dublin Society.
 Sheffield Technical School.
 South Staffordshire Institute of Iron and Steel Works Managers.
 South Staffordshire Ironmasters' Association.
 South Wales Institute of Engineers.
 University College of South Wales.
 West of Scotland Iron and Steel Institute.

COLONIAL AND FOREIGN.**Colonial.**

Canadian Institute.
 Canadian Mining Institute.
 Canadian Society of Civil Engineers.
 Department of Mines, Sydney.
 Department of Mines, Melbourne.
 Geological Survey of Canada.
 Geological Survey of India.
 Geological Survey of New South Wales.
 Mining Society of Nova Scotia.
 Royal Society of New South Wales.

United States.

Alabama Industrial and Scientific Society.
 American Association for the Advancement of Science.
 American Institute of Mining Engineers.
 American Iron and Steel Association.
 American Society of Civil Engineers.
 American Society of Mechanical Engineers.

United States.

Department of Labour.
Engineers' Society of Western Pennsylvania.
Franklin Institute.
New York Academy of Sciences.
Ordnance Office, War Department.
School of Mines, Columbia College, New York.
Smithsonian Institute.
United States Geological Survey.

Austria.

K.k. geologische Reichsanstalt.
Oesterr. Ingenieur und Architekten-Verein.

Belgium.

Association des Ingénieurs sortis de l'Ecole des Mines de Liège.
Ministère de l'Intérieur.

France.

Comité des Forges.
"Revue Maritime." Ministère de la Marine.
Société d'Encouragement pour l'Industrie Nationale.
Société de l'Industrie Minérale.
Société des Anciens Elèves des Écoles Nationales d'Arts et Métiers.
Société des Ingénieurs Civils.
Société Scientifique Industrielle de Marseille.

Denmark.

Tekniske Foreningen.

Germany.

Königliche Bergakademie in Freiberg.
Königliche Technische Versuchsanstalt.
Verein Deutscher Eisenhüttenleute. (Journal "Stahl und Eisen.")
Verein Deutscher Ingenieure.

Italy.

Reale Accademia dei Lincei.

Sweden.

Jernkontoret.

JOURNALS.

The following periodicals have been presented by their respective Editors :—

UNITED KINGDOM.

- “British Trade Journal.”
- “Coal and Iron.”
- “Commerce.”
- “Contract Journal.”
- “Colliery Guardian.”
- “Electrician.”
- “Electrical Engineer.”
- “Engineer.”
- “Engineer and Iron Trades Advertiser.”
- “Engineering.”
- “Engineers’ Gazette.”
- “Hardwareman.”
- “Hardware Trade Journal.”
- “Industries and Iron.”
- “Invention.”
- “Iron and Steel Trades Journal.”
- “Iron and Coal Trades Review.”
- “Ironmonger.”
- “Ironmongery.”
- “Iron Trade Circular.”
- “Machinery Market.”
- “Marine Engineer.”
- “Mechanical Engineer.”
- “Phillips’ Monthly Register.”
- “Plumber and Decorator.”
- “Practical Engineer.”
- “Railway Engineer.”
- “Railway World.”
- “Science and Art of Mining.”
- “Shipping World.”
- “Statist.”
- “Steamship.”
- “The London Technical Education Gazette.”
- “Tool and Machinery Register.”

COLONIAL AND FOREIGN.

Colonial.

- “Canadian Mining Review.”
- “Indian and Eastern Engineer.”
- “Indian Engineering.”

United States.

- "Age of Steel."
- "American Journal of Science."
- "American Manufacturer."
- "Bradstreet's."
- "Cassier's Magazine."
- "Engineering and Mining Journal."
- "Engineering Magazine."
- "Engineering News."
- "Iron Age."
- "Iron Trade Review."
- "Letter of the Anthracite Coal Operators' Association."
- "Metallographist."
- "Mines and Minerals."
- "Railroad Gazette."
- "Report of Proceedings of the Master Car Builders' Association."
- "Tin and Terne."

Austria.

- "Oesterr. Zeitschrift für Berg- und Hüttenwesen."

Belgium.

- "Bulletin de l'Union des Charbonnages de Liège."
- "Moniteur des Intérêts Matériels."
- "Revue Universelle des Mines."

France.

- "Annales des Mines."
- "L'Echo des Mines."
- "Le Génie Civil."
- "Portefeuille Économique."

Germany.

- "Annalen für Gewerbe und Bauwesen."
- "Chemiker Zeitung."
- "Glückauf."
- "Verein Deutscher Eisen und Stahl Industrieller."
- "Zeitschrift für das Berg-, Hütten- und Salinenwesen im preussischen Staate."
- "Zeitschrift für praktische Geologie."
- "Zeitschrift für Werkzeugmaschinen und Werkzeuge."

Italy.

- "L'Industria."
- "Rassegna Mineraria."

Spain.

- "Revista Minera."

Sweden.

- "Teknisk Tidskrift."

SECTION II.

*NOTES ON THE
PROGRESS OF THE HOME AND FOREIGN
IRON AND STEEL INDUSTRIES.*

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In the preparation of these Notes the Editor has been assisted by E. J. BALL, Ph.D.,
H. G. GRAVES, Assoc. R.S.M., and G. KAMENSKY, Assoc. R.S.M.

IRON ORES.

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I.—OCCURRENCE AND COMPOSITION.

The Rosedale Ironstone Mines.—R. Richardson gives an interesting account of the famous ironstone mines at Rosedale, North Yorkshire. All the ironstone mined at the East Mines is now got by electrical power, and the mining company, who had secured a lease of an additional 600 acres of land on the Danby royalty, are extending their mines in the direction of Fryup Head, on the Whitby side. In the year 1849 an old fisherman, walking over the moors to his home at Whitby, noticed that the roads were being repaired with magnetic ore. He reported the circumstance, with the result that some of the ore was excavated and analysed, and was found to yield no less than 60 per cent. of iron. The formation of the company followed, and since that time some millions of tons of ironstone have been taken from the Rosedale Hills.*

Iron Ore in Austria.—J. Lowag † describes the occurrence of iron ore, chiefly magnetite and red hæmatite, near Kleinmohrau, in Austrian Silesia. The ore occurs in beds up to three yards in thickness in chlorite schist of Lower Devonian age. The ore was mined until 1870, when the blast-furnaces were stopped owing to the cost of charcoal, and the mines have not been worked since that date.

* *Colliery Guardian*, vol. lxxvi. p. 1029.

† *Glückauf*, vol. xxxv. pp. 163-165.

Iron Ore in France.—N. de Mercey * ascribes the origin of the hydrated iron ore of Neocomian age at Briey to the superficial alteration of carbonate of iron, and shows by the results of numerous borings the continuity in depth and the importance of the carbonate.

The Minette Deposits of German Lorraine.—W. Albrecht † describes that portion of the minette deposits of German Lorraine which extends to the north-west of the Deutsch-Oth fault. This district is at a much higher level than the others, and consists geologically wholly of Dogger beds. The geological conditions are described in detail, and the author then passes to a consideration of the work that has so far been done in the district in question. A number of analyses are given of the various iron ore seams that are met with. These include the following :—

| | Black Bed. | Grey Bed. | Red Bed. | Calcareous Bed. |
|--|------------|-----------|-----------|-----------------|
| | Per Cent. | Per Cent. | Per Cent. | Per Cent. |
| H ₃ PO ₄ | 1.600 | 2.600 | ... | ... |
| Mn | trace | trace | trace | ... |
| H ₂ CO ₃ | 4.120 | 1.940 | ... | ... |
| S | 0.084 | 0.112 | ... | ... |
| P | 0.690 | 1.030 | 0.788 | 0.72 |
| Fe | 39.080 | 39.390 | 42.00 | 28.20 |
| SiO ₂ | 19.470 | 16.400 | 12.00 | 9.69 |
| Al ₂ O ₃ | 4.690 | 5.610 | 6.21 | 3.73 |
| CaO | 5.850 | 5.470 | 5.18 | 21.13 |
| MgO | 0.350 | 0.250 | 0.31 | 0.21 |
| H ₂ O | 8.860 | 11.240 | ... | ... |
| Fe ₂ O ₃ | 45.980 | 56.280 | ... | ... |
| Fe(OH) ₂ | 8.860 | | ... | ... |
| H ₂ SO ₄ | 0.210 | 0.180 | 0.11 | 0.09 |

Other partial analyses which are given state the percentage of iron in the black seam at about 35 to 42 per cent. of iron.

At the Adlergrund mines on the French-German frontier the black ore seam is met with, and has there a thickness of about nine feet. It is of soft earthy character and markedly shows the presence of carbonate in places. Analysis shows it to contain—

| | | |
|-------|-------|---------|
| Iron. | Lime. | Silica. |
| 42.38 | 5.6 | 12.47 |

The grey seam is also found. In places it is not worth mining, and in others it is of a good and satisfactory character. An analysis showed—

| | | |
|-------|-------|---------|
| Iron. | Lime. | Silica. |
| 40.38 | 4.91 | 15.21 |

* *Comptes Rendus de l'Académie des Sciences*, vol. cxxvii. pp. 1245-1248.

† *Stahl und Eisen*, vol. xix. pp. 305-316 and 354-360, with plates and illustrations.

The red seam is split by numerous very thin partings. In one place the author found twenty-seven of them. A portion of this seam, nearly 15 feet in thickness, contains—

| Iron. | Lime. | Silica. |
|-------|-------|---------|
| 36.31 | 5.25 | 20.08 |

The calcareous seam is divided into two benches, the upper of which contains a higher percentage of iron.

Similar details are given in connection with a number of other workings, and other seams are also mentioned and analyses given. They are of a similar character to those mentioned above.

In the Hessinger deposit, which occurs in a side valley of the Adler deposit, the so-called "black" seam has a green, grey, or black colour, and contains many small ore masses having the composition—

| Iron. | Lime. | Alumina. | Silica. |
|-------|-------|----------|---------|
| 27.49 | 17.78 | 4.02 | 14.12 |

and has the average composition—

| Iron. | Lime. | Alumina. | Silica. |
|-------|-------|----------|---------|
| 41.06 | 2.40 | 5.60 | 16.94 |

The "grey" seam, also occurring here, has the average composition—

| Iron. | Lime. | Alumina. | Silica. |
|-------|-------|----------|---------|
| 42.08 | 1.81 | 4.28 | 17.39 |

An intermediary seam between this "grey" seam and the "red" seam is occasionally met with, and contains—

| Iron. | Lime. | Alumina. | Silica. |
|-------|-------|----------|---------|
| 38.84 | 4.87 | 6.87 | 15.20 |

The "red" seam has in this deposit the composition—

| Iron. | Lime. | Alumina. | Silica. |
|-------|-------|----------|---------|
| 35.32 | 8.42 | 4.22 | 19.94 |

The calcareous seam is here poor in iron. The "yellow" seam is stated to have the following composition in the case of another deposit—

| Iron. | Lime. | Alumina. | Silica. |
|-------|-------|----------|---------|
| 40.50 | 9.61 | 8.03 | 6.50 |

Dealing generally with the deposits, the author observes that to make use of the colour of the ore as a means for naming the seam is not justified, the degree of oxidation of the ore varying very greatly. The varying thicknesses of the ore seams is largely due to the fact that portions of them often show themselves in the form of "partings." The partings themselves are often to be considered merely as poor iron ore seams. The red seam, he points out, possesses throughout

the whole district approximately the same percentage composition, and this holds good, too, of the calcareous seams. The grey and black seams become more calcareous and less siliceous towards the north-east. There is, he points out, a distinct connection between the composition of the ore seams and of the adjacent partings. Just, too, as the changes in composition within the ore seams are often rapid and very considerable, so too are they in the partings. The inclosures within the seams really represent a kind of transition phase between the partings and the ore seams. The author shows how the composition of the ore seams is changed or brought about by the leaching action of water containing dissolved gases on the ferruginous limestone and marls of the district.

Iron Ore in Prussia.—O. Vogel* quotes from an interesting old account by Johann Gottlob Lehmann describing the state of the iron industry in Prussia. This was published a hundred and fifty years ago. Incidentally it is mentioned that iron ore was found to grow again in abandoned mines, new ore being observed after the lapse of a few years, though its quality was not so good as before. He mentions the existence of two blast-furnaces between Skodnia and Grashow. At these the ore smelted was partly obtained from Tarnowitz and partly mined locally, and he refers to the formation of zinciferous bears in the furnace, which were as bad as when Gosslar ores were smelted. Two other blast-furnaces are mentioned as existing near Butkowitz.

Iron Ore in Hungary.—H. Ullmann† describes the iron ore beds at Petrocz, in Bihar County, Hungary. The ores are met with at five points. The richest deposit is at Magura Saca, where a deposit of red hæmatite outcrops for a length of $1\frac{1}{2}$ mile and a width of $1\frac{1}{4}$. The ore yields 36 per cent. of iron. It occurs in limestone and is easy to smelt. There is an abundant supply of water power, of labour, and of cheap charcoal in the vicinity. The ore can be quarried at 1s. per ton, so that the manufacture of charcoal pig iron should prove a remunerative undertaking.

Iron Ore in Portugal.—Considerable attention is being devoted to the iron ore deposits of Portugal.‡ Red and brown hæmatite

* *Stahl und Eisen*, vol. xviii. p. 1110.

† *Montan-Zeitung*, vol. vi. pp. 115-117.

‡ *Zeitschrift für Praktische Geologie*, 1890, p. 149.

deposits occur at Cuba in South Alemtejo, and on the bank of the Zezere, in North Alemtejo, there is a bed of brown hæmatite yielding 55 to 58 per cent. of iron, 0·3 to 0·5 per cent. of phosphorus, and no sulphur. Until means of communication, however, are improved, work on a large scale is impossible.

Iron Ore in Russia.—Iron ore is becoming scarce in Southern Russia. The Krivoi Rog mines are nearly exhausted, and while there are other sources from which supplies can be drawn, they are not large enough to depend upon for increased business. At the present rate of consumption the Krivoi Rog deposit will not last for more than 15 or 20 years, and consequently ore is advancing in price, and manufacturers are looking for new sources from which to draw future supplies.*

Manganese Ore in Spain.—In the Spanish province of Huelva there are numerous deposits of manganese ore. The mean depth of these beds is 40 yards. They were first worked in the middle of this century, and operations continued until 1883. From 1858 to 1883 the output was 450,000 tons, the maximum output being 36,000 tons in 1878. Owing to the discovery of other sources of supply of black oxide of manganese, the mines remained unworked until the demand for manganese in the steel industry led to their being reopened, the exports having amounted in 1895 to 30,000 tons, in 1896 to 80,600 tons, and in 1897 to 87,200 tons. The ore is worked open-cast, and is hand-picked at a cost of 8s. a ton. As sent to market it contains 35 to 40 per cent. of peroxide. An export duty of 5d. per ton is imposed, and the cost of transport and harbour dues has to be borne. Consequently ore with less than 35 per cent. of peroxide cannot be exported at a profit.†

The Iron Ores of Northern Sweden.—In view of the recent visit to Sweden of the Iron and Steel Institute, a full and illustrated account, which has appeared in *Stahl und Eisen*,‡ of the Lulea-Ofoten Railway, and the ore deposits it opens up, is of considerable interest. The history of the railway and its construction is in the first place dealt with, and then the deposits themselves are described.

The Kiirunavaara and Luossavaara iron ore fields form the largest

* *Mining Journal*, vol. lxviii. p. 1329.

† *Der Grwm.*, vol. i. pp. 254-255.

‡ Vol. xix. pp. 61-68, 143-146, 165-169, 221-223, 329-333, with illustrations.

ore deposits of this kind in Scandinavia. They consist chiefly of magnetite, with which red hæmatite is frequently associated. Both deposits have been known since the beginning of the eighteenth century. The first references to the Kiirunavaara deposits are found in a document of a date between 1696 and 1727. In 1736 the ore deposit was examined by a specially appointed Commission, and in 1770 plans were prepared for mining operations and smelting works, but nothing came of this. Some ore was obtained from Luossavaara in 1764 and iron made from it at Junosuando, but this proved red-short. It was only at the beginning of the eighties in the present century that any working of this deposit on a large scale was thought of, but it was not until the commencement of the present decade that the present mining company was formed, the railway having then been built.

The Kiirunavaara ores form a stock-work which extends for a length of about $2\frac{1}{2}$ miles, and rises in the form of a hill whose summits vary from 269 feet to rather more than three times this height above the level of the adjacent lake. The ore dips at an angle of from 50° to 60° towards the east. It varies from about 110 to about 500 feet in thickness, diminishing apparently with depth, although this is as yet still uncertain. The quantity of ore in sight above the level of the lake is estimated at 215 millions of tons, besides what lies below this level.

In the Luossavaara field there are several ore deposits. These are mostly covered with overburden. Magnetic observations and actual work have shown that the largest of these ore deposits has a length of at least nine-tenths of a mile, while the thickness of the ore varies from about 100 to 165 feet. It dips inwards at its southern end at an angle of 75° , and its mass diminishes with depth. It is not possible at present to make any calculation as to the quantity of ore it contains, except that it may be estimated that above the level of the lake there are some 18 millions of tons of ore. This ore is everywhere high in iron, and comparatively free from impurities. It is very dense and hard too, and often so shattered that when blasted it falls into small pieces, though never into powder. With regard to its phosphorus contents, it can be divided into several kinds. The most important of these are the following :—

- | | |
|-----|---|
| (1) | Ore with 0·03 or less to 0·1 per cent. of phosphorus. |
| (2) | „ 0·1 „ 0·8 „ „ |
| (3) | „ 0·8 „ 1·5 „ „ |
| (4) | „ 2·0 „ 6·0 „ „ |

Ores with less than 0·05 per cent. of phosphorus are found at the northern and southern ends of Kiirunavaara and Luossavaara. They are frequently so mixed with ores containing up to 0·1 per cent. or more of phosphorus that their separation from them is either difficult or impossible. The last kind of ore chiefly occurs at Luossavaara, but very phosphoric ore is also found there. Ore with from 0·1 to 0·8 per cent. of phosphorus occurs in large quantities, but the greater part of the Kiirunavaara ore is higher in phosphorus, containing generally over 1 per cent., frequently 2 to 3 per cent., and for a considerable distance along the deposit from 4 to 5 per cent. of phosphorus. This Kiirunavaara deposit may be considered indeed as higher in phosphorus than any other large deposit of iron ore. The phosphorus occurs in the ore in the form of apatite, which is present either in a very fine state of dissemination in the ore or else in larger pieces. It is not, however, in any case capable of separation from it by ordinary dressing methods to such an extent as to leave an ore low in phosphorus. Apart from apatite other impurities are of rare occurrence. The percentage of iron in the ore is very high. Thus in 60 per cent. of the places sampled at the Kiirunavaara deposit the percentage of iron varied from 67 to 71, and in 21 per cent. from 60 to 67. The average for the Luossavaara deposit was from 67 to 70·55 per cent. Boreholes have shown that the ore is subject to the same variations in composition in the deep as are observable at the surface. The percentage of sulphur in the ore rarely exceeds 0·05 to 0·08 per cent. Titanium also occurs in the ore, being present in that of the Kiirunavaara deposit in percentages of from 0·32 to 0·95, and in the Luossavaara ore from 0·94 to rather more than 1. The ore occurs as stock-work-like deposits in a porphyry of a very variable character. This porphyry district is surrounded at the east and west by bedded sedimentary rocks. It is probable that other similar ore deposits exist, though as yet undiscovered, in addition to those now described. The question of the distribution of the apatite, with the resulting difficulty in sampling, is discussed in detail, illustrations being given to show the mode of occurrence of the apatite in the ore. It has been found possible in several cases, by careful separation, to obtain from ore rich in phosphorus ore with less than 0·05 per cent., but the difficulties are too great to make this a commercial success, and it is best not to attempt to deal with the richer ore as such. The sampling has shown that ores with less than 0·05 per cent., and with from 0·05 to 0·10 per cent., occur by themselves in quantities sufficient for mining purposes.

Leaving the question of phosphorus and passing to that of sulphur, it is pointed out that pyrites has only been observed at a few spots at or near the surface. It therefore seemed probable that the percentage of sulphur would prove even less than analysis has shown to be the case. The sulphur observed in the iron obtained in the case of some dry assays made in 1875 varied from 0·03 to 0·08 per cent. in the case of sixteen samples, from 0·10 to 0·12 in six samples, and up to 0·15 in other six samples. In 1896 and 1897 large samples were taken, to the number of seventy-four. In three samples taken from the same open working the percentage of sulphur varied from 0·105 to 0·117 per cent. In no other case, however, did it exceed 0·088. As a rule, it was about 0·05 per cent., and not infrequently less than 0·02.

With regard to the titanium, four analyses made in 1875 showed from 0·32 to 0·6 per cent. of titanium dioxide, while other recent samples have shown from 0·45 to 0·75 per cent.

The percentage of manganese was determined in the case of three samples in 1896 and 1897. The results were respectively 0·20, 0·18, and 0·32 per cent. The following are complete analyses:—

II.

| | Per Cent. | Per Cent. |
|----------------------------------|-----------|-----------|
| Magnetic oxide of iron | 96·250 | 71·150 |
| Ferric oxide | 1·620 | 25·320 |
| Manganous oxide | 0·260 | 0·260 |
| Lime | 0·400 | 0·300 |
| Magnesia | 0·310 | 0·220 |
| Alumina | 0·390 | 0·560 |
| Silica | 0·950 | 1·850 |
| Phosphorus pentoxide | 0·008 | 0·086 |
| Sulphur | 0·033 | 0·030 |
| Totals | 100·221 | 99·776 |

No. I. was a general sample taken from magnetite from the Vaktmäster, Kiirunavaara, and No. II. a similar sample from a working to the south of the summit of Luossavaara. It will be seen that No. I. corresponds to a contents of 70·80 iron and 0·004 phosphorus, and No. II. to 69·23 per cent. of iron and 0·03 of phosphorus.

In the Norbotten Province, in addition to the enormous deposits of Kiirunavaara and Luossavaara, there are numerous smaller iron ore fields, the best known of which is the Svappavaara, about twenty-five miles E.S.E. of Kiirunavaara. For every metre depth it is thought there is at Svappavaara 180,000 tons of ore to be won, and down

to a depth of 300 metres some fifty millions tons of ore are believed to be available, if not more. The ore is somewhat high in phosphorus, averaging over 1 per cent., and it contains about 60 per cent. of iron. It is therefore not so rich an ore as that of the Kiirunavaara deposit. Other ore deposits in the same district are those of Junosuando, Lappäkoski, Sontusvaara, and Nakerijoki. The last named was discovered in the summer of 1897. It has been pointed out by Vogt that all the known large deposits of iron ore in Northern Sweden are at very considerable distances from the Finland border, and that the geological formation containing these deposits ends, so far as is now known, about sixty miles from that border. It is therefore improbable that ore fields will be found in Northern Finland, but if such are discovered, the ore from these, as well as from those above mentioned, must find its transport by way of Ofoten. For every metre sunk the following are the probable ore quantities available :—

| Deposit. | Metric Tons. |
|--|--------------|
| Kiirunavaara - Luossavaara | 1,900,000 |
| Svappavaara | 180,000 |
| Gellivare | 750,000 |
| Grangesberg (Central Sweden) | 145,000 |

In the Gellivare district the output now amounts annually to 600,000 tons of ore, but it is unlikely that for any long series of years its output can exceed one million tons. At Grangesberg the annual output is also about 600,000 tons, but depth is being attained at this deposit with some rapidity, and it is unlikely that mining on its present scale will last at this deposit for any very lengthened period. The ore deposits feeding the Ofoten line of railway, on the other hand, will probably last for at least a couple of centuries, even with an output of three million tons of ore a year.

The question of transport is also considered.

In a comparison of the Kiirunavaara, Ofoten, and Gellivare-Lulea deposits and transport lines, it is pointed out that the Kiirunavaara ores will cost about half a Swedish crown less per ton to mine than the Gellivare ores, and that the advantage as to cost of transport, &c., will also be slightly in favour of the Kiirunavaara lines. The output of the latter will have, however, to be double that mined from the Gellivare deposits if the railway opening up the former is to pay its way. In all probability the monetary advantage in favour of the

Kiirunavaara ore is likely to be about one Swedish crown per ton. This refers to ore mined open-cast; but while in the Gellivare district it may perhaps be necessary to employ deep mining in the course of the next ten years, open-cast working, even with an annual output of three million tons, is possible in the Kiirunavaara district for some fifty years to come.

Ore from the Koskulls deposit, which is connected by railway with Gellivare, is to be raised at the rate of 60,000 tons a year. The Witkowitz Ironworks will draw its supply of Swedish ore from this field.*

D. A. Louis † gives a general description of the iron ore deposits at Gellivare with a number of photographs of the principal mines.

Iron Ore in Ontario.—W. Murdoch and W. J. Morris ‡ publish an interesting account of the mineral resources of Ontario. Iron ore is found in great abundance. In the valley of the Ottawa River there are extensive deposits of fine compact hæmatite, and a short distance westerly are found hæmatite and magnetic ores of excellent quality assaying 57 to 68 per cent. of iron. Farther west, to the north of Kingston and towards the eastern end of Lake Ontario, are also found thick beds of high-grade magnetite. On the shores of Lake Huron specular iron ore is found. The known iron ore deposits of Ontario, within easy access of means of transport, are sufficient to supply the world's requirements for a century to come.

Iron Ore in Nova Scotia.—The annual report of the Geological Survey of Canada § contains a monograph on the geology of South-West Nova Scotia by L. W. Bailey. Iron ores occur in the district in abundance, both in beds and veins. The ores are chiefly red hæmatite and magnetite. Some of the beds are composed of the well-known fossil ore. There are enormous quantities of this ore available, and in view of the easy means of communication between the deposits and some of the coalfields, the economic importance is considerable.

Manganese Ore in Nova Scotia.—W. F. Jennison || describes the manganese ore deposits of Nova Scotia. The ores, placed in order

* *Stahl und Eisen*, vol. xix. p. 51.

† *Engineering Magazine*, vol. xvi. pp. 610-623.

‡ *Financial News*, December 15, 1898.

§ Vol. ix., Report M., pp. 5-154.

|| *Journal of the Federated Canadian Mining Institute*, 1898, pp. 167-172.

of their importance, are pyrolusite, psilomelane, braunite, manganite, and hausmannite. They are found in the manganiferous limestones of the Lower Carboniferous series, the chief deposits being at Tennycap, Pembroke, Walton, and Colchester, in Hants county. At Tennycap the ore is found in pockets in brecciated limestone, in lenticular veins in massive limestone, and lowest of all in regular veins in a shaley limestone. The latter is not much worked, although it is richest, because of the lack of proper dressing machinery.

Iron Ore in New Jersey.—The annual report of the Geological Survey of New Jersey shows that the mineral production is less important than it has been, owing to the exhaustion of some of the iron mines and the gradual transfer of the iron industry of the country westward to the region where cheap fuel and the Lake Superior iron ores are accessible. There is still a considerable output of iron ore, however, and the clay industry is important.

The Rich Patch Iron Ore, Virginia.—H. M. Chance * describes the Rich Patch iron ore district, which covers about three by six miles in Alleghany county, Virginia. Two kinds of ore are found—the red hæmatite or fossil ore of the Clinton formation, worked in Alabama, and the brown hæmatite or Oriskany ore, of which there are two beds. Only the lower one has been worked, but the upper bed is also of considerable importance. The ore contains 42 to 55 per cent. of iron, and averages 47 to 49, but it could be raised to 50 per cent. with more careful preparation. At present the ore as shipped contains 15 to 19 per cent. of silica, and usually below 0·3 per cent. of phosphorus with no sulphur, and about 0·5 per cent. of manganese. Mining commenced in 1890, and a description is given of the workings, mostly open-cast, although some levels have been driven.

Iron and Manganese Ore in Cuba.—According to J. S. Cox † the iron ore deposits in the province of Santiago, Cuba, mostly lie in the Sierra Maestra between Manzanillo and Cape Maysi, along the south-eastern coast of the island, five to ten miles inland. The country appears to be the result of the upheaval of coral reefs by syenite subsequently overflowed by ferruginous trap. The ore outcrops on the tops of the hills are considered by some as replacement deposits. The

* *Transactions of the American Institute of Mining Engineers*, New York Meeting 1899.

† *Engineering Magazine*, vol. xvi. pp. 745-758.

Juragua deposits, which supply several companies in the United States, are fifteen miles from Santiago harbour. Before 1893 they shipped nearly 1,400,000 tons, but in that year other deposits were opened up to compete. Amongst these were the Sigua deposits, east of Juragua and twenty miles from Santiago, but the ore here soon became too lean. Also to the east and four miles from the port of Daiguiri there is an excellent group of mines, and a good steel dock and pier for shipping the ore. Cuban ore is generally a Bessemer hæmatite, but is rather high in sulphur, due to veins of pyrites, but that mineral may be partly removed by cobbing. The deposits are all worked open-cast, and the ore is loosened by large blasts. Inclined planes take the ore down to the railways.

Manganese ore is worked at the Ponupo and nine other groups of mines in this province, but the mining methods at present are very primitive.*

Iron Ore in the Philippines.—According to a report to the Secretary of the United States Navy, prepared by G. F. Becker, there is iron ore in abundance in Luzon, Caraballo, Cebu, Panay, and doubtless in other islands. In Luzon it is found in the provinces of Laguna, Pampanga, and Camarines Norte, but principally in Bulacan. The finest deposits are in the last-named province, near a small settlement named Camachin, which lies in lat. $15^{\circ} 7'$ and long. $124^{\circ} 47'$ east of Madrid. A small industry exists here, wrought iron being produced in a sort of bloomery and manufactured into ploughshares. It would appear that charcoal pig iron might be produced to some advantage in this region. The lignites of the archipelago are probably unsuitable for iron blast-furnaces.†

Iron Ore in China.—In an account of a journey down the Yellow River, China, M. S. Welby ‡ observes that a large portion of the population of Shui-Tsui-Tsi is engaged in iron-working. All the way down the river from Chong Wei the author passed through a district very rich in coal, and he observes, "Judging from the number of smithies in Shui-Tsui-Tsi, the district must possess very considerable mineral wealth."

* *Mines and Minerals*, vol. xix. pp. 109-110.

† *Colliery Guardian*, vol. lxxvi. p. 939.

‡ "Through Unknown Tibet," p. 365. London, 1898.

Iron Ore in Japan.—According to Paul Jordan,* Japan is poor in iron. Veins of iron ore occur in Iwate, and magnetic iron sands are abundant in Shimane, Tottori, and Hiroshima. These three districts produce a little iron, but it is made by ancient processes, and is unsuitable for many purposes. In 1894 the whole empire produced only 15,760 tons of pig iron, 4015 tons of wrought iron, and 932 tons of steel.

Recent Researches on Meteorites.—H. L. Preston † describes the San Angelo meteorite, weighing 194 lbs., and found in Texas in 1897. Widmanstätten figures are well developed, troilite nodules are scarce. An analysis shows, in addition to traces of cobalt and carbon, with a possible trace of manganese :—

| Fe. | Ni. | Cu. | P. | S. | Si. |
|--------|------|------|-------|-------|-------|
| 91.958 | 7.86 | 0.04 | 0.099 | 0.032 | 0.011 |

H. S. Washington ‡ describes the Jerome meteorite from Kansas, found in 1894, and weighing about 60 to 70 lbs. Its approximate composition is :—

| Soluble. | | | Insoluble. | |
|--------------|-----------|------------|------------|------------|
| Nickel Iron. | Troilite. | Silicates. | Chromite. | Silicates. |
| 4.25 | 5.16 | 54.47 | 0.87 | 35.25 |

Fuller analyses are also given.

J. M. Davison§ has found that platinum, and probably iridium, occur in two Mexican meteorites, one from Coahuila and the other from Toluca.

H. L. Ward|| gives an illustration of a meteorite weighing 417 grammes from Ness county, Kansas. No analysis is given.

P. Melikoff¶ and W. Krschischanowsky state that a meteorite fell on June 9, 1889, at the village of Migheja, in the Kherson government. It forms a somewhat fragile mass, containing disseminated amorphous carbon, and gives a black streak on paper. When rubbed, the meteorite evolves a characteristic smell, resembling that of bituminous bodies. It contains free sulphur, thiosulphates, sulphates, and sulphites. Only

* *Annales des Mines*, vol. xiv. pp. 530-556.

† *American Journal of Science*, vol. v. pp. 269-272.

‡ *Ibid.*, pp. 447-454.

§ *Ibid.*, vol. vii. p. 4.

|| *Ibid.*, p. 233.

¶ *Zeitschrift für anorganische Chemie*, vol. xix. p. 11.

a portion of the nickel is soluble in mercuric chloride. An analysis shows :—

| | Per Cent. |
|---|-----------|
| Silica | 27·49 |
| Lime | 2·11 |
| Magnesia | 19·85 |
| Ferrous oxide | 26·95 |
| Manganous oxide | 0·65 |
| Sodium oxide | 1·37 |
| Potassium oxide | 0·17 |
| Alumina | 1·62 |
| Ferrous sulphide | 0·46 |
| NiFe ₃ | 3·95 |
| Chromite | 1·62 |
| Phosphorus | 0·15 |
| Free sulphur | 3·10 |
| Sulphuric anhydride | 0·85 |
| S ₂ O ₂ | 0·12 |
| Amorphous carbon | 2·63 |
| Hygroscopic moisture | 1·40 |
| Organic matter and undetermined | 5·51 |
| Total | 100·00 |

The soluble silicate consists chiefly of olivine of the composition $3(\text{MgO})_2\text{SiO}_2 \cdot 2(\text{FeO})_2\text{SiO}_2$. The insoluble silicate is a bisilicate of the augite group. In addition to amorphous carbon, it contains hydrocarbons, recalling by their smell heavy petroleum residues.

Emil W. Cohen * gives a summary of the literature and a detailed description of the structure of the following meteoric irons :—

(1) *Campo del Cielo, Gran Chaco Gualamba, Argentina*.—This is a granular to compact ataxite, composed of nickel iron having the composition of kamacite. The etched surface appears, to the unaided eye, finely granular and homogeneous, but with a lens it shows characteristic ridges and hollows, and, by deeper etching, wrinkled etch-faces.

(2) *Siratik, Senegal, West Africa*.—This iron in structure and composition closely resembles the Campo del Cielo iron. It is possible that different specimens under this name may belong to different falls.

(3) *Santa Rosa, Colombia, South America*.—This mass of iron weighs about 1650 lbs. It is an octahedral iron of coarse structure (Zacatecas group).

(4) *Tocavita, near Santa Rosa*.—Certain fragments, labelled as Santa Rosa, are found to belong to a different type; these it is proposed to distinguish as “Tocavita,” after the name of the hill where they were found. The structure is octahedral, with very fine lamellæ, closely resembling that of the Ballinoo iron. It is further distinguished by

* *Annalen k.k. naturhistorisches Hofmuseum*, vol. xiii. pp.

the presence of much rhabdite, sometimes in large crystals. A determination of the phosphorus gave 0.52 per cent., corresponding with 3.38 per cent. of rhabdite.

(5) *Rasgata, Colombia*.—This is an ataxite, and closely resembles the Santa Rosa meteorite in composition.

(6) *Linnville Mountain, Burke County, North Carolina*.—This is an ataxite rich in nickel.

(7) *Chesterville, Chester County, South Carolina*.—A granular to compact ataxite poor in nickel.

(8) *Kokomo, Howard County, Indiana*.—In the granular structure and in the composition this resembles the Cape of Good Hope iron.

(9) *Iquique, Tarapaca, Peru*.—In structure and composition this resembles the last.

Analyses of these nine meteorites gave the following results:—

| | Fe. | Ni. | Co. | Cu. | Cr. | C. | P. | S. | Cl. | Totals. |
|-------|-------|-------|------|------|-------|------|------|-------|-------|---------|
| I. | 94.25 | 5.11 | 0.57 | 0.03 | 0.03 | 0.06 | 0.18 | 0.05 | trace | 100.28 |
| II. | 94.07 | 5.21 | 0.77 | 0.01 | ... | 0.01 | 0.26 | 0.04 | ... | 100.37 |
| III. | 92.30 | 6.52 | 0.78 | 0.02 | trace | 0.18 | 0.36 | 0.04 | nil | 100.20 |
| IV. | 89.81 | 9.77 | 0.57 | 0.02 | trace | 0.03 | 0.22 | 0.06 | nil | 100.48 |
| V. | 92.81 | 6.70 | 0.64 | 0.01 | trace | 0.19 | 0.28 | 0.08 | trace | 100.71 |
| VI. | 83.13 | 16.32 | 0.76 | 0.02 | ... | 0.11 | 0.23 | 0.02 | ... | 100.59 |
| VII. | 93.80 | 5.50 | 0.75 | 0.02 | trace | 0.02 | 0.34 | 0.03 | nil | 100.46 |
| VIII. | 83.24 | 15.76 | 1.07 | 0.01 | ... | ... | 0.08 | trace | ... | 100.16 |
| IX. | 83.49 | 15.41 | 0.34 | 0.02 | trace | 0.03 | 0.07 | 0.02 | ... | 99.98 |

According to Emil W. Cohen,* in the previous description of the meteoric iron from Beaconsfield, it was stated that carbon having the appearance of anthracite was present; this was found after dissolving the meteoric iron in dilute hydrochloric acid and treating the residue with cupric ammonium chloride, in order to separate the taenite and cohenite from the schreibersite and rhabdite. It is now found that this anthracitic carbon is not an original constituent of the iron, but is formed by the action of the cupric ammonium chloride on the cohenite. Although cohenite, Fe_3C , contains only about $6\frac{1}{2}$ per cent. of carbon, this carbonaceous residue is compact and shining. The crystals of cohenite from the Toluca and Beaconsfield irons give homogeneous solid pieces, whilst the crystalline aggregates of cohenite from the Niakornak iron give finely granular carbon possessing little cohesion.

It is suggested that some anthracites—for example, that of mineral veins—may have been formed by the alteration of carbides, which are now known to be of terrestrial origin.

* *Königliche Akademie der Wissenschaften Sitzungsberichte*, 1898, pp. 306-307; *Journal of the Chemical Society*, vol. lxxvi, p. 113.

According to Emil W. Cohen,* four fragments of a meteoric iron were brought to Europe in 1896 from the San Cristobal gold-mining district, near Antofagasta, in Chili; one of the fragments weighs 60 grammes. Troilite nodules are surrounded by a zone of schreibersite, and this again by a zone of dark nickel iron. The main mass of the iron shows an intricate structure on the surface; this appears to be due to minute lamellae, which are much bent and twisted. Putting aside the Oktibbeha County and Santa Catharina irons as being doubtfully meteoric, this iron differs from all other meteorites in the high percentage of nickel and in its peculiar structure; it is, therefore, placed in a special class of the ataxites. Analysis gave—

| Fe. | Ni. | Co. | P. | Total. | Specific Gravity. |
|-------|-------|------|------|--------|-------------------|
| 73.72 | 26.60 | 1.00 | 0.18 | 100.50 | 7.8593 |

Manganese Ore in Brazil.—M. Ribeiro Lisboa † gives a detailed account of the manganese ores of Brazil. The deposits occur in the States of Matto Grosso, S. Paulo, and Minas Geraes. Twelve analyses given by the author show the proportion of manganese to vary from 40.73 to 57.40 per cent. The ore is sent to Rio de Janeiro, and shipped to England and the United States.

It is only in Minas Geraes, ‡ however, that manganese ore is mined, and that only within the past four years. The deposit mined is stated to extend for a distance of hundreds of miles between Lafayette and Marianna on the Central Railway. The central points of the present workings are at Queluz and Miguel Burnier, 4000 feet above sea-level, and in a good climate. These two places have stations on the line, and are distant some 290 miles from Rio de Janeiro. It takes some ten or twelve days for the transport of the ore to the latter place. The ore is stated to contain from 50 to 53 per cent. of manganese, and the percentage of phosphorus is very low. The percentage of moisture and volatile matter contained in the ore is about from 10 to 15 per cent. Up to the present only open-cast methods of working are in use, the ore being simply quarried and then conveyed to the main line of railway either in ox-waggons or by means of light railways. The cost of mining was at first only 3 milreis the ton, but this has now increased to from 12 to 15 milreis. Were proper methods of mining adopted, however, it is thought that the cost could be reduced

* *Königliche Akademie der Wissenschaften Sitzungsberichte*, 1898, pp. 607-608; *Journal of the Chemical Society*, vol. lxxvi. p. 113.

† *Revue Universelle des Mines*, vol. xlv. pp. 1-22.

‡ *Deutsches Handelsarchiv; Stahl und Eisen*, vol. xix. p. 48. 1899.—i.

to 6 milreis. The ore is conveyed on the railway in open 12-ton waggons to Rio de Janeiro, but these have to be emptied and others reladen at the station of Lafayette, where the narrow and broad gauge lines make connection. The railway charge is about 10-140 milreis per metric ton from the stations at the mines to the port. The freights from there to the United States and the United Kingdom are about nine or ten shillings per ton. The present price is such as to enable the ore to be sold at a considerable profit. The exports have up to now been as follows:—

| | Tons. |
|----------------|--------|
| 1894 | 1,390 |
| 1895 | 5,490 |
| 1896 | 14,120 |
| 1897 | 8,800 |

While for 1898 the estimated output is 20,000 tons. In 1894-96 the ore was sent to Middlesbrough, and in 1897 to Philadelphia.

Chrome Iron Ores.—J. H. Pratt* deals with the occurrence, origin, and chemical composition of chromite. The American deposits are dealt with, and it is stated that the mineral is always found in peridotite rocks. The chromite masses nearly always occur near the boundaries of the lenticular masses of peridotite, not in well-defined veins, but in apparently unrelated masses. The large deposits seen have always been in the peridotite and near its boundary with the inclosing gneiss. When the chromite occurs as grains, these are most numerous along the contacts, and diminish toward the centre of the peridotite mass. This peculiarity tends to show that the chromite was held in solution in the molten peridotite when this was intruded into the country rock, and that it was among the first minerals to separate out as the mass began to cool. Such an origin accounts for the pockety nature of chromite deposits, the way they widen or pinch out, and their apparent lack of relation. A review of the various analyses of chromite is given, and the probable formulæ for the chemical composition of different samples are appended.

J. H. Pratt† has published another paper on the chemical composition of chromite and of its occurrences, and discusses the probable origin of the deposits. In North Carolina, extending from Ashe county to Clay county, there is a series of disconnected peridotite outcrops, and

* *Annals of the New York Academy of Sciences*, vol. xi. p. 489.

† *Transactions of the American Institute of Mining Engineers*, New York Meeting, 1899.

chromite is associated with them. It is, however, in few localities only that the mineral has been found in considerable quantity, and there has never been any systematic development, though the ores are all of high grade. A description of the principal localities is given.

Some notes on the supply, occurrence, and concentration of chrome iron ore have appeared.* The principal supplies of chromite are drawn from Turkey, Russia, Greece, California, Canada, New Caledonia, and New South Wales. Of these countries Turkey and Russia are reported to be the largest producers. The various deposits are briefly reviewed.

The chrome-mining industry is remarkable for the irregularity in the occurrence of the mineral conditions. The chrome ore is almost always found in serpentine, when it is easily mined, but it usually occurs in small pockets, which are soon exhausted; indeed, as a rule, the deposits are too small to warrant the outlay of much capital for their exploitation, and mining is consequently comparatively expensive. Hand-picking is chiefly used in the preparation of the ore, but there is a field for dressing machinery.

At one works in California the process is carried out as follows:—The ore is crushed by the breaker and the Huntingdon mill so as to pass a 40-mesh sieve. The pulp is separated on vanners. The concentrates are collected in settling tanks, whence they are removed to the drying floors, and finally packed for shipment in strong jute bags. The following analyses give the results:—

| | Crude Ore. | Concentrates. |
|-----------------------------------|------------|---------------|
| Sesquioxide of chromium | 43.70 | 52.86 |
| Ferrous oxide | 14.80 | 15.45 |
| Alumina | 15.96 | 11.59 |
| Magnesia | 16.49 | 16.26 |
| Silica | 7.96 | 3.00 |
| Lime | 0.66 | 0.76 |
| Water | 0.49 | 0.10 |
| | 100.06 | 100.02 |

The use of the ore for furnace lining is also referred to.

Nickeliferous Magnetites.—According to W. G. Miller,† samples of ore from the larger deposits of titaniferous magnetite in Eastern

* *Iron and Coal Trades Review*, vol. lvii. p. 823.

† *Report of the British Association*, vol. lxvii. pp. 660-661; *Journal of the Chemical Society*, vol. lxxvi. p. 109.

Ontario have been found to contain nickel (and cobalt) to the extent of 0·8 per cent. No nickel has been found in the non-titaniferous magnetites of the district. The former are considered to be of igneous origin, and the latter of aqueous or mechanical origin. The high quality of iron extracted from the titaniferous ores may be due to the presence of nickel.

Nickel Ore.—T. Ulke* describes the methods of mining nickel ore in Canada and New Caledonia, the roasting of Canadian ore, smelting for matte and bessemerising it, the Orford process or separation-smelting, reverberatory refining by the English method, the wet process and electrolytic refining. A number of illustrations are given and some statistics are included.

The extraction of nickel from its ores by the Mond process has been described by Sir William Roberts-Austen.† The subject has also been dealt with by J. E. Stead.‡

II.—IRON ORE MINING.

The Lake Superior Iron Ore Mines.—In a paper read on February 14, 1899, J. Head and A. P. Head§ gave the results of their investigations into the routes of ore-ships, the methods of loading, unloading, and transportation of the ore to blast-furnaces in the Lake Superior iron ore region. This region comprised five ore "ranges"—viz. (1) Marquette, (2) Menominee, (3) Gogebic, (4) Vermilion, (5) Mesabi. Of these, the Marquette was the earliest and the Mesabi the most recently developed. The aggregate output from the five ranges in 1897 was over 120 million tons of ore. The mines were situated within 100 miles of the shore of Lake Superior. The ores were taken to the nearest Lake port, and were then transported into ships for distances varying between 509 miles and 925 miles to the ore-receiving ports. The ores were hæmatites, and usually occurred on a bed of diorite or quartzite, below which was green schist or granite; above the ore was surface drift or slate. The four mining methods employed were (1) overhead stoping, (2) caving, (3) milling, (4) steam-shovelling.

* *Engineering Magazine*, vol. xvi. pp. 215-226, 451-456.

† *Minutes of Proceedings of the Institution of Civil Engineers*, vol. cxxxv. pp. 29-53.

‡ *Proceedings of the Institution of Cleveland Engineers*, 1898-99, pp. 119-120.

§ *Minutes of Proceedings of the Institution of Civil Engineers* (advance proof).

In the overhead stoping method, a slanting shaft was sunk in the foot rock, and the ore body pierced by a cross heading. This was driven longitudinally for a short distance, and the ore was worked out upwards, being followed up by scaffolding, until the surface soil was reached. The timber was then blasted down, allowing the surface to cave in. Pillars were left between such workings, and were subsequently removed by the caving method. In the caving method shafts were sunk and headings driven through the ore body. Rises were worked upwards to the under-surface of the soil, and connected together by passages. A slice of ore, 7 feet thick, was then worked out over the whole area, the roof being timbered. The props were subsequently blasted away, and the surface fell in to a depth of 7 feet. A second slice of 7 feet was then removed, the ground being allowed to fall in to this further extent; the operation was then repeated. In the milling method a shaft was sunk and a heading driven through the ore body. From this, side drifts were made and rises cut upwards to the surface of the ore, which had previously been stripped and laid bare. The ore was dug out and shovelled down the rises into tubs below, to be afterwards wound up the main shaft. Less timbering was required in this method, and the chief operations were carried on in the open air. The steam-shovelling or open-cut method was by far the cheapest, but was applicable to only five mines, where the physical condition of the ore resembled earth and where the deposit was near the surface. The steam-shovels weighed 92 tons, and could fill a 25-ton waggon with ore in $2\frac{1}{2}$ minutes. The Mountain Iron Mine, in the Mesabi district, was a typical open-cut mine. Mesabi ores, owing to their pulverised condition, could only be used to the extent of 30 per cent. to 40 per cent. of the charge in the blast furnace. The ore cost 10d. per ton on trucks in the Mesabi district, and as much as 4s. 2d. per ton in districts where older and more expensive methods were used. Sampling for the testing of ores was highly systematised, as many as 5000 samples contributing to one analysis. In sales and purchases of ore the analysis was assumed to be 63 per cent. of iron, 0.045 per cent. of phosphorus, and 10 per cent. of moisture, the prices varying according to a sliding-scale, depending on the divergence of the actual analysis from the standard. The ore shipping docks had been brought to a high state of efficiency. They consisted of jetties, each with four lines of rail from end to end. The contents of ore waggons were discharged through bottom doors into pockets, each of which held 175 tons. They were 12 feet apart from centre to centre, and their floors sloped in opposite directions

on the two sides of the centre line of the jetty. As the hatches of the ore ships were mostly 24 feet apart, alternate pockets could be emptied simultaneously through spouts into a steamer lying alongside. The storage capacity of the Duluth docks was 100,000 tons, and the current rate of loading was 1000 to 1600 tons per vessel per hour. The ore ships were of peculiar construction, being limited in draught to about 17 feet, having twelve to fourteen hatches, and with a carrying capacity of as much as 6000 tons. On their way from Lake Superior to Lake Erie these vessels passed through the Saulte Ste. Marie locks, where a difference in level between Lakes Superior and Huron of 27 feet occurred. The locks comprised two belonging to the United States and one to Canada, the latter being 900 feet long by 60 feet wide, and completed in 1895 at a cost of £700,000. Large stocks of ore were kept at ore-receiving ports on Lake Erie, those at Cleveland varying between 8,000,000 tons at the end of the shipping season in November to 1,000,000 tons at the commencement thereof in April. The unloading of the ore was accomplished by machinery of the "Brown hoisting" type. This consisted of a number of bridges arranged in groups of four: each bridge operated three buckets, which were in turn dropped into the hold of the ship, filled by hand, and the contents deposited either on to stock-piles or direct into waggons. The speed of unloading had reached 750 tons per ship per hour. The railway ore traffic from ore-receiving ports to the smelting centres was worked by large locomotives, weighing 127 tons, hauling as many as thirty waggons, with a total load of 1600 tons of ore. The railway rates on some lines are $\frac{1}{2}$ d. per ton per mile. A comparative table of the estimated cost of producing pig iron at Pittsburg and Middlesbrough seems to show that at the former place the cost was probably about £1, 8s. 9½d., and at the latter about £2, 8s. 10d. A comparative table of selling prices showed that in steel rails, steel ship-plates, and steel billets and blooms, Pittsburg prices were considerably below Middlesbrough prices. The authors believed that Lake Superior iron ores, aided by Pennsylvania fuel, were likely to have a permanent effect in cheapening iron and steel throughout the world, and should tend to encourage the production of such goods, and especially of ocean-going ships and engines in the United States ports to an unprecedented extent.

N. P. Hulst* describes the various methods used for mining iron ore in the Lake Superior district. Particular attention is given to the mining of hard ore at the Soudan mine on the Vermilion range, the

* *Proceedings of the Engineers' Society of Western Pennsylvania*, vol. xv. pp. 62-104.

systems at the Chapin mine, Menominee range, the settling and caving systems at the adjacent Pewabic mine, at the Lake Angeline mine in the Marquette district, at the Queen group of mines at Negaunee in the same district, and at the Chandler mine on the Vermilion range. The milling system at the Auburn mines and the steam-shovel systems in the open works of Biwabik and Mahoning mine are also dealt with. Numerous plans, sections, and illustrations are given, and this paper may be advantageously read in conjunction with Head's account given above.

The shipments of ore from the five great ranges of the Lake Superior district have been as follows : *—

| | 1897. | 1898. |
|---------------------|------------|------------|
| | Tons. | Tons. |
| Marquette | 2,715,035 | 3,125,039 |
| Menominee | 1,937,013 | 2,527,274 |
| Gogebic | 2,258,236 | 2,498,461 |
| Vermilion | 1,278,481 | 1,265,142 |
| Mesabi | 4,280,873 | 4,613,766 |
| | 12,469,638 | 14,029,682 |

A table is also published † showing the shipments for the last forty-three years by ranges and by mines.

Timbering in Iron Ore Mines.—J. L. Hedley ‡ and W. Leck describe the methods of timbering in use in the iron ore mines of Cumberland and Furness. Scarcely any use is made of masonry or of iron and steel, and timber, mainly larch and pine, is used in the shafts and workings. The various forms are described in detail with the aid of numerous illustrations.

The Hasselmann Impregnation Process for Mine Timber.—In the Hasselmann § method for the impregnation of timber intended for use in mines and elsewhere, the wood is stated to be impregnated throughout its mass, and not merely on the surface. The wood after treatment is much harder than it was before. The method consists in forcing in under a pressure of from 1 to 3 atmospheres, according to

* *Iron Trade Review*, January 26, 1899, p. 8.

† *Ibid.*, February 2. Supplement.

‡ *Transactions of the Institution of Mining Engineers*, vol. xvi. pp. 281-290, with two plates.

§ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlvi. p. 654.

the nature of the wood, a solution having a temperature of from 100° to 140° C. This solution contains aluminium and iron sulphates, calcium chloride, and other substances. It is stated that after treatment the salts cannot be removed even by lengthened boiling with water. The wood, too, need not be dried before being submitted to this process. M. Krause also describes this process.*

Rock-Drills.—An illustrated description of the Dinnendahl and the Brandt rock-drills has been published.† The former is a rotary drilling machine driven by compressed air, a ring being cut in the rock the diameter of the level required. It also bores a hole in the centre of the section of the level. The Brandt machine is also a rotary drilling machine. It is driven, however, by hydraulic power. It has a hollow steel drill, consisting of a ring with two to five teeth, which cut the rock, whilst water for flushing the borehole is carried down the interior of the drill.

Further illustrated descriptions have appeared ‡ of the latest forms of Siemens electric percussive rock-drills.

At the mines of St. Andreasberg, in the Hartz, experiments § have been made with the rubber hose connecting the rock-drills with the air compressor. It was found that spiral windings of wire produced swellings which led to the hose wearing badly. Wire netting was rapidly worn away, and was uncomfortable to handle. Cotton outer casings soon rot under the action of damp. The best results were obtained with smooth rubber hose of $\frac{3}{4}$ inch inside diameter, and $\frac{1}{2}$ inch thick with an inside linen lining.

Electric Boring.—Electric boring has been introduced at the spathic iron ore mines of the Kotterbach valley in Upper Hungary. The plant is designed for the simultaneous operation of fifteen Siemens and Halske rock-drills. At the present time five are in use and three in reserve. Power is supplied by a 35 horse-power steam-engine. The mines are worked by four main adit levels, and electric boring is carried on at each of these. The shift lasts twelve hours, two men and a lad being employed at each drill. ||

* *Gluckauf*, vol. xxxiv. pp. 760-764.

† *Uhland's Technische Rundschau*, 1899, No. 1.

‡ *Iron and Coal Trades Review*, vol. lvii. pp. 780-782.

§ *Zeitschrift für das Berg-, Hütten- und Salinenwesen im preussischen Staate*, vol. xlv. p. 104.

|| *Berg- und Hüttenmannische Zeitung*, vol. lviii. pp. 133-134.

Cost of Tunnelling.—An interesting statement of the cost of tunnelling in Colorado has been brought before the American Institute of Mining Engineers by W. C. Ralston. The actual cost (exclusive of management) of 2608·5 ft. of tunnel, 7 ft. by 8 ft., at the Melones Mine up to September 24, 1898, was as follows :—

| | Actual Cost. | Cost per Running Foot. |
|--|--------------|------------------------|
| | Dols. | Dols. |
| Labour (including timbering) | 19,501·46 | 7·47 |
| Powder, 27,550 lbs., and fuse 74,000 ft. | 3,405·65 | 1·30 |
| Caps, 200 boxes | 500·20 | 0·19 |
| Wood, 333½ cords | 1,667·50 | 0·63 |
| Water | 828·50 | 0·32 |
| Coal, 11,591 lbs. | 179·43 | 0·06 |
| Planks | 169·32 | 0·06 |
| Candles, 3040 lbs. | 262·04 | 0·10 |
| Steel rails, 21,555 lbs. | 567·62 | 0·22 |
| Air pipe and water pipe | 1,042·45 | 0·45 |
| Horse feed | 267·16 | 0·10 |
| Steel, oil, tools, &c. | 316·92 | 0·12 |
| Totals | 28,708·25 | 11·02 |

Thus the actual cost per running foot was about £2, 4s.

The Occurrence of Fire-Damp in Iron Ore Mines.—J. Libert * records five cases in which fire-damp has been encountered in iron ore mines in the province of Namur. He ascribes its production to the decomposition of timber. This was the view adopted by Bennett H. Brough in his paper on gas in metalliferous mines read before the North of England Institute of Mining Engineers in 1889.

G. Nordenström † finds that inflammable gas issuing from borings in the Dannemora Mine contains 33·6 per cent. of marsh gas, and 66·4 per cent. of nitrogen. In this case the gas has certainly not been derived from the decay of timber under water.

The Kley Pump.—K. Habermann ‡ describes at considerable length, and with many illustrations, the Kley steam-pumping plant at the Franz Shaft, Idria.

Iron Ore Transport.—An interesting paper on the transportation of Lake Superior iron ore is contributed by E. B. Taylor. §

* *Annales des Mines de Belgique*, vol. iv. pp. 48-54.

† *Geologiska Föreningens i Stockholm Förhandlingar*, vol. xviii. pp. 637-640.

‡ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlvii. pp. 27-32, 39-44.

§ 53-56, 72-75, 83-86, 94-97, with two sheets of illustrations.

§ *Proceedings of the Engineers' Society of Western Pennsylvania*, vol. xiv. pp. 210-238.

The improvements of the last ten years have been remarkable, and ore is now being handled at a cost that twenty years ago would have been thought impossible. The extended use of steel in the Great Lake and ocean steamers, in the larger locomotives, in the ore waggons, in the heavier rails, and in various structural materials, has been made possible by the discoveries of rich ores that can be cheaply mined. When ore is loaded on railway waggons at a cost of 2d. per ton, the mining cost is obviously down almost to the vanishing-point.

Illustrations have appeared* of the Brown revolving derrick installed at Punxsutawney, Pennsylvania, for handling ore. It is a cantilever crane with a span of 357 feet and a trolley travel of 350 feet, and it runs on a circular track 40 feet in diameter.

S. Miller† describes the wire rope-ways as applied to open-pit mining, and gives illustrations of the various appliances in use.

G. E. Walsh‡ gives some illustrations of several of the large steamers used on the great American lakes for the transport of iron ore.

III.—MECHANICAL PREPARATION.

The Magnetic Concentration of Iron Ore.—E. Primosigh§ discusses the Gröndal-Bellwik process for the magnetic concentration of iron ores. The author observes that at Pitkaranta, in Finland, magnetic iron ore occurs in large quantities, but it is too poor in iron and too much mixed with sulphides to be of use as an iron ore in its native condition. Among the sulphides that occur with the iron ore are zinc blende and copper pyrites. The percentage of iron is rarely above 25, and is frequently below 20. The ore, too, is expensive to crush fine enough for separation, as well as difficult to separate after being so crushed. For ten months, however, at the time the author wrote, a concentrating plant had been successfully at work, its capacity being 350 tons of ore a day. In magnetic separation the chief cost lies in the first crushing of the ore. This must be crushed fine enough to admit of a proper separation, but the separation itself is independent of the exact size or shape of the crushed particles. In connection with this plant the Gruson ball-mills were first employed in crushing

* *Iron Trade Review*, January 26, 1899, pp. 14-15.

† *Journal of the Federated Canadian Mining Institute*, 1898, pp. 173-188.

‡ *Cassier's Magazine*, vol. xv, pp. 499-507.

§ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlvii, pp. 51-53.

the ore, but though at first they gave satisfaction, this was not the case in the long-run. They require dry material to work on, and this necessitated an occasional drying of the ore. Then, too, they made an excessive quantity of dust, which in itself quite forbade their use for magnetic concentration purposes. A modified form of ball-mill was subsequently designed, which gave satisfaction. This the author describes. The magneto-separators each consist of two rotating cylindrical portions, one of these being the true separator. This consists of four ring-shaped electro-magnets attached at their axes, and separated at their ends by brass rings. The second cylinder consists of eight concentric rows of points of soft iron, of two kinds, placed in a wooden drum. These points are brought in front of the magnets, induction takes place, and the ore flies from the magnets to the iron points. As they pass away from the magnets the ore falls from them again, and is readily removed. A separator requires 0.5 horse-power. The electro-magnets require a current of 35 volts and 8 amperes. According to the percentage of iron contained in the ore, one separator will treat in twenty-four hours from 25 to 50 tons of ore. The concentrates contain from 65 to 71 per cent. of iron. These concentrates are converted into briquettes by mixing with from 3 to 5 per cent. of lime, pressing, and then allowing to stand for a fortnight; or the wet ore may be raised to a sintering heat—700° to 800° C.—after first pressing into briquettes. The author gives details as to the cost of the process.

With the available water-power of 125 to 150 horse-power, the cost of installing a plant for treating 120,000 to 150,000 tons of ore annually is as follows:—

| | Horse-Power. | Cost. |
|------------------------------------|--------------|--------------|
| Two ore-breakers | 12 | £ |
| Two elevators | 4 | 160 |
| Eight ball-mills | 96 120 | 2000 |
| Eight separators | 4 | 1580 |
| Dynamios, &c. | 4 | 160 |
| Pump | 4 | 65 |
| Transmission and belting | | 520 |
| Buildings | | 650 |
| Erection | | 985 |
| Total | | £6500 |

The cost of concentration is about 6d. a ton.

Magnetic concentration is also described by Leo* and by Schiff.†

* *Stahl und Eisen*, vol. xix. pp. 271-273.

† *Génie Civil*, vol. xxxiv. pp. 188-189.

REFRACTORY MATERIALS.

Fireclay.—According to Kiesewatter,* a large deposit of fireclay has recently been discovered near Hintermeilingen in Hesse-Nassau. It rests on basalt and is divided into three sharply defined beds. The lowest (1) is chocolate-brown in colour; the middle layer (2) bluish-white; and the upper layer (3) reddish-white in colour. These are separated by a few feet from each other. Analyses of these three seams have given the results shown in the following table:—

| | I. | II. | III. |
|----------------------------|-----------|-----------|-----------|
| | Per Cent. | Per Cent. | Per Cent. |
| Silica | 49.30 | 52.24 | 51.93 |
| Alumina | 33.75 | 32.39 | 32.33 |
| Ferric oxide | 1.39 | 1.61 | 1.61 |
| Lime | trace | nil | trace |
| Magnesia | trace | nil | nil |
| Alkalies | 1.63 | 1.89 | 1.89 |
| Loss on ignition | 14.50 | 11.67 | 11.67 |
| Totals | 99.97 | 99.80 | 99.98 |

Other burnt samples showed from 36.38 to 38.61 per cent. of alumina. The clay showed itself to be of a highly fire-resisting character, I. being a little better than the Seger cone No. 34, and II. and III. somewhat better than the Seger cone No. 33.

A detailed description has been published by Hans von Post † of the occurrence of fireclay at Hoganäs and Skromberga in Sweden.

Bauxite.—G. L. Bourgerel ‡ discusses the formation of bauxite. The bauxites occurring in the south of France are of various colours. The red is used for the manufacture of aluminium, and the white for the preparation of sulphate of alumina, intermediate varieties being

* *Thonindustrie Zeitung*, vol. xxii. p. 783.

† *Teknisk Tidskrift*, vol. xxix. pp. 38-40.

‡ *Revue Scientifique*, vol. xi. p. 699.

mixed with plastic clay and made into firebricks. The red variety contains 62 to 50 per cent. of alumina, 24 to 28 per cent. of ferric oxide, and 1 to 7 per cent. of silica; whilst the white contains 74 to 65 per cent. of alumina, 0·25 to 3 per cent. of ferric oxide, and 12 to 18 per cent. of silica. The bauxite bed is 50 yards in thickness and occurs in limestone. Its formation is believed to be due to an interaction between quicklime and hot concentrated solutions of aluminium and iron chlorides.

Graphite.—Max Diersche* publishes an exhaustive description, covering 58 pages, of the graphite deposits of Ceylon. The chief locality is Ratnapura in the south of the island, where graphite occurs as a gneiss. The exports of graphite from Ceylon represent a value of £430,000 annually. The mineral is obtained by quarrying, the workings being in the hands of natives. About 250 to 300 men are employed. Ceylon graphite is the best material for the manufacture of crucibles.

* *Jahrbuch der k.k. Geologischen Reichsanstalt*, vol. xlviii. pp. 231-288.

FUEL.

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I.—CALORIFIC VALUE.

The Calorific Value of Coal.—D. de Paepé * gives a long series of tabulated results showing the calorific value of different coals as determined by the Mahler bomb, and as calculated by the Goutal formula. By this formula the calorific value is taken as equal to

$$\frac{8150 C + AM}{100}$$

where C is the percentage of fixed carbon free from ash, M the percentage of volatile matter, and A is a constant varying from 13,000, with 2 to 15 per cent. of volatile matter, and 9000 when M is 35 to 40 per cent. To obtain closer approximation the factor M is replaced by $\frac{100 M}{M + C}$ and a number of values are given for the variable constant A.

C. V. Kerr † describes the Berthier method of coal calorimetry, and gives some results obtained with it. In spite of its inaccuracy, the method is still used on account of its convenience.

* *Bulletin de l'Association Belge des Chimistes*, through the *Colliery Guardian*, vol. lxxvii. p. 155.

† *Colliery Guardian*, vol. lxxvii. pp. 399-400.

Calorific Power of Weathered Coal.—R. S. Hale* and H. J. Williams give the results of some experiments on the calorific power of weathered coal. The results with sealed and with weathered samples are tabulated. Under the conditions described, the percentages of carbon, hydrogen, and nitrogen decreased, oxygen increased, and sulphur was unaffected. The weathering decreased the calorific power by about 2 per cent. as calculated by Dulong's formula, or by about $\frac{1}{2}$ per cent. as determined by the calorimeter.

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Comparative Evaporating Efficiency of Coke and Brown Coal.—W. Gyssling† observes that it was desired at Munich to ascertain whether gas coke or brown coal could best be used for steam-raising purposes. It was necessary that as nearly a smokeless combustion as possible should result. The percentage composition of the coke and brown coal was as follows:—

| | Gas Coke. | Brown Coal. |
|-------------------------------|-----------|-------------|
| | Per Cent. | Per Cent. |
| Carbon | 83.6 | 53.9 |
| Hydrogen | 1.0 | 4.3 |
| Oxygen and nitrogen | 2.0 | 14.7 |
| Sulphur | 0.8 | 0.4 |
| Ash | 9.7 | 2.5 |
| Moisture | 2.9 | 24.2 |
| Totals | 100.0 | 100.0 |

The coke yielded 7009 calories, and the brown coal 4955 calories.

It was found that to obtain the desired quantity of steam it was necessary to burn per hour 78.5 kilogrammes of coke per square metre of grate, or 149 kilogrammes of brown coal. The grate was, it is true, not such as is best adapted for burning brown coal, but even allowing for this, the advantage as to cost was distinctly in favour of the coke.

Pyrometry.—T. H. Waller‡ deals with the measurement of high temperatures, and describes the various forms of pyrometers now in use.

* Paper read before the American Society of Mechanical Engineers, through *cering*, vol. lxvii. p. 67.

† *Journal für Gasbeleuchtung*, vol. ii. p. 29.

‡ Paper read before the South Staffordshire Institute of Iron and Steel Works Managers.

II.—COAL.

Origin of Coal.—W. S. Gresley* discusses the origin and formation of coal, especially in view of the information afforded by microscopic investigations as applied to the seams in Pennsylvania and elsewhere. The drift theory is upheld.

The micro-organisms of coal have been investigated by B. Renault.†

The Chemistry of Coal.—W. C. Anderson‡ gives a contribution to the chemistry of coal with special reference to the coals of the Clyde basin. The author's investigations relate more particularly to the points of difference and reaction between coking and non-coking coals, and a summary of the work in this direction of previous investigators is given. The composition of a number of the Clyde coals is stated, together with the results obtained by extraction with various solvents, treatment with nitric acid, oxidation, and heating. The difference in coking qualities of these coals is tentatively ascribed to certain volatile constituents of resinoid character, but other factors enter the question, which requires further investigation for its solution.

Coal in Staffordshire.—C. E. De Rance,§ in a presidential address to the North Staffordshire Field Club, reviews the geology of the Staffordshire coalfields.

Coal in Kent.—A seam of coal 9 inches thick was struck on April 4 at Ropersole, Barham, midway between Dover and Canterbury, and the discovery proves that the coal strata between Dover and Barham are continuous and that they are practically horizontal. It is thought that Godwin-Austen's theory, advanced forty-three years ago, is amply proved, and that the coalfield of Westphalia traverses Belgium and Northern France across the English Channel to South-East England. The fuel in one seam struck is said to be good bituminous coal. W. Boyd-Dawkins is of opinion that the existence of a coalfield in the south-east of England is now proved.||

* *American Geologist*, vol. xxiii. pp. 69-80, one plate.

† *Naturwissenschaftliche Rundschau*, through the *Colliery Guardian*, vol. lxxvii. p. 798.

‡ *Transactions of the Institution of Mining Engineers*, vol. xvi. pp. 335-357.

§ *Colliery Guardian*, vol. lxxvi. p. 755.

|| *Ibid.*, vol. lxxvii. p. 619.

The Douglas Coalfield, Lanarkshire.—R. Weir * describes the Douglas coalfield, Lanarkshire. Its history is briefly traced; sections are given of the strata, and the various seams are described.

The Correlation of the British and European Coal-Measures.—The correlation of these beds, which come below the millstone grit, is discussed by W. Hind.†

Coal in Austria.—At a meeting of the Natural Science Society of Troppau, Von Schenkenbach read a paper on the brown coal-mines of Sörgsdorf in Austrian Silesia. The deposit was discovered in 1859 by a workman digging for clay. The coal is obtained by quarrying. The output is 1200 tons annually.

Coal in Bosnia.—Poech ‡ discusses the coal industry of Bosnia. The production has increased from 499 tons in 1880—the beginning of the production—to 268,700 tons in 1898. The Zenica Colliery has three workable seams of 7, 3, and 4 yards thickness respectively. The coal, which is liable to spontaneous combustion, contains 6 to 10 per cent. of ash and 2·6 per cent. of sulphur.

Coal in France.—C. Grand'Eury § describes the lignites of Savoy. The beds, which are of Pliocene age, have been known in the valley of Chambéry and Aix-les-Bains for a long time, and in 1877 a concession was granted to work them at Voglans. The workings were eventually abandoned, and a new company has been formed to utilise the product in the form of briquettes. The lignite is pulverised and screened, dried, and compressed into blocks. The crude lignite contains 45 per cent. of moisture. This proportion is reduced to 18 per cent. in the finished briquettes. The briquettes are firm and of good appearance, and burn with a flame. Owing to their cheapness they will no doubt take an important place in the local coal trade.

The Brown Coals of Greece.—C. Zengelis || gives the following analyses of Greek brown coals:—

* *Transactions of the Institution of Mining Engineers*, vol. xvi. pp. 436-446, with map.

† *Transactions of the Manchester Geological Society*, vol. xxvi. pp. 96-118.

‡ *Zeitschrift des Oesterreichischen Ingenieur- und Architekten-Vereins*, vol. li. pp. 123-125.

§ *Comptes Rendus Mensuels de la Société de l'Industrie Minière*, 1898, pp. 185-193.

|| *Chemiker Zeitung*, vol. xxii. p. 648; *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlvi. p. 685.

| | From Kumi. | From Oropor. | From Aliokrion. | From Heraklion. |
|-------------------------------------|---------------|-----------------|--------------------|--------------------|
| | Per Cent. | Per Cent. | Per Cent. | Per Cent. |
| Carbon | 44.04 | 38.99 | 40.24 | 57.01 |
| Hydrogen | 5.17 | 4.03 | 3.32 | 3.91 |
| Nitrogen | 1.64 | 2.51 | 0.97 | 0.79 |
| Sulphur | 2.44 | 1.21 | 0.64 | 2.15 |
| Ash | 20.09 | 19.44 | 7.59 | 4.74 |
| Moisture | 14.09 | 13.72 | 18.69 | 13.02 |
| Yield of coke | 51.60 | 50.09 | 48.70 | 58.60 |
| Calorific power, calories | 5076 | 4764 | 4994 | 6238 |

The Oropor and Aliokrion fuels more resemble lignites than brown coals. Mixed with from 50 to 70 per cent. of bituminous coal these Greek brown coals are used for steam-raising purposes at many works.

Coal in Hungary.—V. Ranzinger* describes the Galla and Bánhida coal deposits of Hungary. He considers that it is certain that the coal deposits of Felső-Galla, Alsó-Galla, and Bánhida are identical with those of the Gran district. The same geological conditions exist in all these places. Upon Triassic limestone lie Eocene fresh-water marls, containing small seams of slaty coal, varying from the thinnest of partings to over a yard in thickness. The upper member of this marl group is formed by the main seam, which is on the average 29½ feet in thickness. On these follow the salt-water beds, containing *Cerithium striatum* and other fossils, the author giving further details as to the succeeding beds and their organic remains. Near Vértes-Somló are Oligocene beds, containing a seam of coal about 6 feet in thickness, which is not worked.

The boreholes that have been put down number forty-three, thirty-six of these having been made in the three districts specially referred to. Of these, only five gave no results, while the other thirty-one reached the main seam at depths of from 160 to 650 feet. This coal-field is surrounded on three sides by the Triassic limestone Vértes hills, while on the fourth side it is open. It thus forms a bay in which the Eocene coal formation could form quietly. The five unsuccessful boreholes were either put down too near the mountains or too far "out to sea," the Eocene beds not having been reached at the depth of 200 or 300 yards to which the boreholes were taken. The main seam of coal is estimated to contain about 140,000,000 tons of coal. The follow-

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlv. pp. 689-691; two

ing are two analyses of this coal, which it will be seen is a brown coal :—

| | I. | II. |
|--------------------|-----------|-----------|
| | Per Cent. | Per Cent. |
| Carbon | 57.05 | 58.26 |
| Hydrogen | 4.35 | 4.70 |
| Oxygen | 15.18 | 14.89 |
| Nitrogen | 0.81 | ... |
| Water | 13.55 | 8.82 |
| Sulphur | 2.68 | 2.87 |
| Ash | 6.38 | 10.49 |
| Calories | 5317 | 5560 |

The seam lies near the line of railway from Budapest to Vienna, and is only distant 43 miles from the latter town. Both as regards the quality of the coal found and the position of the deposit, this brown coal deposit must take the premier position when compared with the Salgó-Tarjan, Gran, and other brown coal deposits of Hungary.

The strike is variable, changing three or four times within a thousand yards, but it is possible to wind through each main winding-shaft some 4 to 6 million tons of coal without having any great working difficulties to encounter. The value of this coal deposit has now been recognised, and a colliery is now being opened up which is intended to have an annual output of some 600,000 tons. Electric power is to be utilised on a large scale. A central plant driven by 900 horse-power is erected for the purpose of supplying the power for three winding-shafts. These three shafts are some 500 to 600 yards from the central power station. The plant in use is described and illustrated. Each pit is provided with a winding-shaft and a ventilating shaft, the latter being so arranged that it could, in case of necessity, be used for winding purposes. There is also to each pit a Pelzer fan with a capacity of 88,291 cubic feet per minute, as well as an underground triplex pump with a capacity of 35.3 cubic feet per minute, and a wire ropeway to the screening floor.

Coal in North Italy.—According to H. Altmann,* the explorations made in the brown-coal field at Peonis and Osoppo, in North Italy, are not sufficient to indicate the extent of the deposit. Boreholes should be put down, for it is extremely probable that deep seams of good brown coal exist at greater depths than those already found.

* *Ungarische Montan Zeitung*, vol. iv. No. 19.

Coal in Russia.—G. Franke,* of the Berlin School of Mines, publishes an exhaustive account of the collieries of the Donetz basin, illustrated by a coloured geological map of the region. The total cost of production of coal in the district is 6s. 7d. per ton.

Brown Coal in Algeria.—E. Dusaugé† gives the results of a geological and economic investigation of the brown coal deposits at Marceau, fifteen miles from Cherchell, an Algerian Mediterranean port. There are three seams, about 13, 7, and 3 feet thick respectively, of Miocene age. A representative sample yielded the following results on assay :—

| Water. | Volatile Constituents. | Fixed Carbon. | Ash. |
|--------|---------------------------|------------------|------|
| 30·8 | 31·2 | 25·4 | 12·6 |

It is considered that a ton and a half of this fuel is equal to a ton of Newcastle coal.

Coal in Canada.—Anthracitic coal from the neighbourhood of Moose Mountains, district of Alberta, North-West Territory, has been analysed by C. C. Hoffmann,‡ of the Geological Survey of Canada, with the following results :—

| | Per Cent. |
|---------------------------|-----------|
| Moisture | 2·74 |
| Volatile matter | 18·62 |
| Fixed carbon | 75·52 |
| Ash | 3·12 |

The seam, which is of Cretaceous age, is said to be upwards of 5 feet in thickness.

Coal in Vancouver Island.—The *British Columbia Mining Record* has published an interesting account of the coal industry of Vancouver Island. As the result of the recent development of mining enterprise in British Columbia, there are prospects of a greatly increased local demand for the Vancouver Island coal.

Coal in Western Australia.—The Collie coalfield, Western Australia, is described by G. Hope.§ The coal is a non-caking bituminous coal, with much moisture but little ash. The field is situated

* *Glückauf*, vol. xxxv. pp. 221-234.

† *Bulletin de la Société de l'Industrie Minière*, vol. xii. pp. 501-527.

‡ *Geological Survey of Canada*, vol. ix., Report R., p. 9.

§ *Iron and Coal Trades Review*, vol. lviii. pp. 63-65, with illustrations.

on the eastern side of the Darling Range, and is now generally considered to be of Mesozoic age. The average of several analyses made by B. Woodward shows:—Water, 11·60; volatile hydrocarbons, 32·10; fixed carbon, 51·20; ash, 4·35; sulphur, 0·90; specific gravity, 1·30. The Coal Measure series, which has been proved to be over 1000 feet in thickness, consists of a series of coal-seams, shales, fireclays, and sandstones, while the greatest number of coal-seams cut in one bore was fourteen, varying from 20 feet down to a few inches in thickness. Many borings have been made in the district, and several collieries are being opened up.

Coal in Rhodesia.—W. F. Wilkinson * gives a sketch map indicating the position of the coalfields and railways in Rhodesia. The principal coalfield is along the Zambesi Valley, and coal has been found at a place called Wankie and at Sengwe. In the Gwaai Valley the most southern outcrop of coal formation occurs at the junction of the Gwaai and Rubi rivers, and a line drawn from that point to the known outcrop on the Sengwe River, and parallel to the Zambesi River, would roughly define the southern limit of Rhodesia's great coalfield. There is another coal area near the Transvaal border, and about 50 miles east of Tuli, but it is of minor importance to the Zambesi coal. At Tuli the coal can be seen outcropping in the bed of the Umzingwani River, and some prospecting shafts put down to the east of the river have picked up the seam, which is said to be 9 feet 6 inches thick, of which 4 feet 6 inches is fair steam-coal. The unfavourable feature is the large occurrence of Trappean or igneous rocks in this district, and it seems probable that the seam or seams will be found to be much broken and disturbed. The coal formation consists of shales and sandstones, which are very flat, and lie probably unconformably on a much older formation, composed of garnetiferous micaceous schists, which are well exposed in the bed of the river. The same sequence of rocks occurs at the coal outcrop in the Mafungabusi district, north of Gwelo.

The Transvaal Coalfield.—W. Peile † gives a general account of the Transvaal coalfield, briefly referring to the chief seams and workings. Six sections taken from various boreholes, &c., are given in detail in an appendix.

* *Journal of the Society of Arts*, vol. xlvii. pp. 209-224.

† *Transactions of the Institution of Mining Engineers*, vol. xvi. pp. 20-31, with map.

Coal in Alabama.—The coal industry of Alabama has been carefully studied by W. B. Phillips* in connection with his investigations of the ironmaking resources of the State. The area of the three coal-fields in Alabama is as follows:—

| | Square Miles. |
|-------------------|---------------|
| Cahaba | 400 |
| Coosa | 150 |
| Warrior | 7,800 |
| Total | 8,350 |

The best and largest seams are in the Warrior field, but for steam and household purposes the Warrior coals are no better than those from the Cahaba field. Nearly one-half of the coal made into coke is washed, there being in operation in Alabama twelve washers with a daily capacity of 5800 tons. Average analyses of the coal from the Warrior coalfield and of the coke made from washed and unwashed coal are given below:—

| | Coal. | Coke from Unwashed Coal. | Coke from Washed Coal. |
|---------------------------|-------|--------------------------------|------------------------------|
| Fixed carbon | 61.51 | 87.02 | 90.48 |
| Volatile matter | 31.48 | 1.02 | 1.11 |
| Ash | 5.42 | 10.12 | 7.50 |
| Sulphur | 0.92 | 1.77 | 0.83 |
| Moisture | 0.67 | 0.07 | 0.08 |

Coal in Arkansas.—H. F. Bain† describes the Bonanza coal-mines in Arkansas. The coal occurs near the base of the upper or western coal-bearing division of the Coal Measures as defined by Winslow, but its exact relations to the coal-bearing beds of Kansas and Missouri are uncertain. It seems not improbable that eventually the Arkansas measures will be found to be the southern equivalents, greatly thickened, of the Des Moines productive formation of the Iowa-Missouri-Kansas field.

The coal is a semi-anthracite, and shows on assay:—

| Moisture. | Volatile Matter. | Fixed Carbon. | Ash. | Sulphur. |
|-----------|---------------------|------------------|------|----------|
| 0.50 | 18.37 | 78.02 | 2.25 | 0.83 |

The seam averages 5 feet in thickness, and is not faulted. It is

* "Ironmaking in Alabama," 2nd edition. Montgomery, 1898.

† *Engineering and Mining Journal*, vol. lxi. pp. 579-580.

worked by pillar and stall, and the coal is blasted from the solid with gunpowder.

The Western Interior Coalfield of America.—H. F. Bain * gives a general description of the western interior coalfield of America, which covers nearly 96,000 square miles in the States of Iowa, Missouri, Nebraska, Kansas, Arkansas, Indian Territory, and Texas. The general stratigraphy is briefly reviewed, and then the several sections of the field are dealt with in some detail. The nature of the coal and the markets are also referred to.

Coal in Dakota.—E. J. Babcock † describes the beds of brown coal met with in North Dakota. A number of samples were analysed, with the following average results :—

| | Per Cent. |
|-------------------------------------|-----------|
| Water and volatile matter | 48.37 |
| Fixed carbon | 44.71 |
| Ash | 6.92 |
| Sulphur | 0.34 |

Coal in New Mexico.—Two seams of coal occur in the Salado district of New Mexico, both being about 5 feet in thickness.‡ Assays show :—

| | Water. | Volatile Matter. | Coke. | Ash. | Sulphur. |
|-------------------------------|--------|------------------|-------|-------|----------|
| Ayers or upper seam | 1.27 | 38.22 | 47.10 | 13.40 | 0.645 |
| Akers or lower seam | 0.77 | 41.25 | 46.95 | 11.02 | 0.735 |

Coal in Ohio.—J. W. Jones§ deals with the geology of South-Eastern Ohio, and refers to the ferruginous limestones, coals, and fire-clays of the district. Several seams from 3 to 7 feet in thickness are found, and a brief description is given of them.

The Blossburg Coalfield, Pennsylvania.—A. Hardt|| describes the Blossburg coal-basin, Pennsylvania, where the measures are about 200 feet in thickness, containing nine seams. Only four of these are persistent, and they do not average more than $3\frac{1}{2}$ feet in thickness. A number of assays are given of these seams, showing that the fixed carbon ranges from 67 to 76 per cent. Sections of the strata at the

* *Transactions of the Institution of Mining Engineers*, vol. xvi. pp. 185-210.

† *Mines and Minerals*, vol. xix. p. 254.

‡ *Ibid.*, vol. xix. pp. 123-124.

§ Paper read before the Ohio Institute of Mining Engineers, January 1899.

|| *Mines and Minerals*, vol. xix. pp. 126-127.

various mines are given, and some details of the methods of mining and dressing the coal are appended.

Coal in Washington.—The mines of the Northern Pacific Coal Company at Roslyn, Washington, are fully described.* The coalfield is of an unusually uniform character, and the one seam at present worked will probably last for twenty-five years, as it has been traced over an area of 15 square miles. The coal is a good coking variety of Cretaceous age, with a calorific power of 12,668 British thermal units. Analysis shows it to contain 52·65 per cent. of fixed carbon, 39·70 per cent. of volatile matter, 4·55 per cent. of ash, and 3·10 per cent. of moisture.

Coal in Mexico.—J. Fleury † describes the coal-mines of San Felipe and El Hondo, in the State of Coahuila. At El Hondo there are three seams of coal, the main seam being 3 feet in thickness, whilst at San Felipe there are but two. The coal at El Hondo has a specific gravity of 1·37, and yields on analysis:—

| | Per Cent. |
|---------------------------|-----------|
| Water | 0·6 |
| Volatile matter | 18·0 |
| Ash | 7·5 |
| Fixed carbon | 73·9 |

The coal is a good coking variety, and is of Upper Cretaceous age.

Coal in Chili.—Marco Chiapponi ‡ describes the coal found at Magallanes. It is a brown coal similar to that found in Italy, in Greece, and in France. It has a specific gravity of 1·351, and is found on analysis to contain 48·0 per cent. of fixed carbon, 24·0 per cent. of water, and 11·5 per cent. of ash.

Coal in Peru.—W. Griffith § states that anthracite coal has for a long time been known to exist at various points in the Andes Mountains of Peru, but up to the present time, however, there has been no use for it, as lignite has been preferred.

There were two principal regions examined by the author. The Northern or Tuco field lies in the northern part of the department of Cajamarca, about 50 miles north of the ancient Inca city of the

* *Mines and Minerals*, vol. xix. pp. 193-195.

† *El Minero Mexicano*, vol. xxxiii. pp. 169-172.

‡ *Boletín de la Sociedad Nacional de Minerarva, Santiago de Chili*, vol. x. pp. 304-310.

§ *Journal of the Franklin Institute*, vol. cxlvii. pp. 227-241, with plans and sections.

same name. The other, about 100 miles south of the first, in the department of Libertad, is the Southern or Chicama field, but other fields are reported. A description of the geology and topography of these districts is given, together with an account of the deposits as far as they have been explored. On assay the coal shows:—

| | Tuco. | Chicama. |
|---------------------------|--------|----------|
| Water | 1.450 | 1.596 |
| Volatile matter | 5.633 | 3.030 |
| Fixed carbon | 83.620 | 90.906 |
| Sulphur | 0.554 | 0.652 |
| Ash | 8.743 | 3.816 |

Lignite from Tierra del Fuego.—J. J. J. Kyle* has analysed specimens of lignite from Slogget Bay, Tierra del Fuego, Argentine Republic. One of these contains 39.47 per cent. of fixed carbon, and has a calorific power of 3482 calories. It is a lignite of excellent quality, of a jet-black colour.

The Coal Resources of Siberia.—Gribassow† has published the following details concerning the production of coal in Siberia in the *Almanac of the Commerce and Industry of Siberia*, issued at Tomsk:—

| | 1892. | 1893. | 1894. | 1895. | 1896. |
|---------------------------------------|--------|--------|--------|--------|--------|
| | Tons. | Tons. | Tons. | Tons. | Tons. |
| 1. The Kirghiz Steppe | 1,744 | 1,645 | 1,579 | 3,134 | 1,866 |
| 2. The Basin of Kouznetsk | 19,547 | 16,677 | 20,219 | 20,203 | 22,608 |
| 3. Maritime District | 12,800 | 11,814 | 18,528 | 18,356 | 17,681 |
| 4. The South Yeniseisk | ... | ... | 329 | 508 | ? |
| 5. The South Usuri District | ... | ... | ... | 671 | ? |
| Total for Siberia | 34,091 | 30,136 | 40,655 | 42,872 | ? |

Some particulars of the deposits are appended.

Further notes‡ on the coal resources of Siberia in relation to the Trans-Siberian railway deal with the Kouznetsk basin, the Kirghiz Steppe, the Saghalien coalfields, the Irkutsk collieries and the coalfields of Afoninsk, Bachatsk, Eastern Siberia, and Kirchiaksk Mountains.

* *Anales de la Sociedad Científica Argentina*, vol. xlv. pp. 236-237.

† *Iron and Coal Trades Review*, vol. lviii. p. 14. ‡ *Ibid.*, pp. 151-153.

According to R. L. Dunn,* the area of the Vladivostok coalfield, over which at many points anthracite and bituminous coals have been discovered, is approximately 10,000 square miles. On the line of the railway the coal formations begin to appear within 10 versts of Vladivostok. About 30 versts from the city the railway leaves the anthracite and bituminous Coal Measure outcrop, but immediately enters an area containing extensive beds of lignite, a railway cut at 32 versts exposing a 6-foot seam. The anthracite and bituminous area lies to the east of the railway, and is substantially bounded on the south by the coast-line. The east and west extent of the field along this line is in the vicinity of 100 miles. The north and south extent is less defined to the north, but is about 100 miles north and east.

Active prospecting is going on for coal throughout this area, and the discoveries of outcrops made, demonstrate the existence of a very large quantity of coal. The beds discovered, some anthracite, some bituminous, range from a few inches to 30 feet in thickness. The dips observed range from 37° to 65°. The anthracites analysed were all white ash coals, but ranged in ash from 5 to 30 per cent. Of the bituminous, the ash ranged from 4 to 35 per cent. Some samples were coking, some non-coking, some were excellently suited for marine use. One sample obtained from a 6-foot seam 5 versts from the railroad and only 16 versts (11 miles) from Vladivostok, gave an analysis of 40 per cent. volatile matter, 54 per cent. fixed carbon, 4 per cent. white ash, no clinker, 2 per cent. water. In all of the samples analysed the sulphur ranged from a trace to 0·25 per cent. Some samples produced a hard, fine-grained coke. At only two points had any mining been done.

Coal in Saghalien.—The coal resources of the Island of Saghalien, off the east coast of the Maritime Province of Siberia, are described.† At the present time four coal deposits are being worked. The coal is a gas-coal, containing 1·7 to 1·8 per cent. of ash. Analysis gave the following percentage results :—

| | I. | II. |
|----------------------|-----------|-----------|
| | Per Cent. | Per Cent. |
| Carbon | 85·43 | 84·91 |
| Hydrogen | 6·29 | 5·91 |
| Oxygen | 8·28 | 7·71 |
| Coke yield | 62·40 | 67·76 |

* *Engineering and Mining Journal*, vol. lxvii. p. 293.

† *Ungarische Montan Zeitung*, vol. iv. No. 20.

The total annual coal production of the island is 11,842 tons. Since 1895 the coal has been better screened, and there is now a good demand for it for the Russian Navy and for East Indian steamships.

Coal in Tonkin.—Solomiac* discusses the use of Tonkin coal as a fuel for locomotives. The coal is very pure, its average composition being as follows :—

| | Per Cent. |
|--------------------|-----------|
| Carbon | 88·3 |
| Hydrogen | 3·6 |
| Oxygen | 2·5 |
| Nitrogen | 1·1 |
| Sulphur | 0·4 |
| Ash | 2·6 |
| Water | 1·5 |

He gives a drawing of the type of locomotive best adapted for burning this anthracite.

Lignite in Siam.—H. Warington Smyth,† in a recent work on Siam, deals at some length with the tin and other mining industries of that country, and also refers to some of the lignite deposits on the west coast of the Malay Peninsula. An outcrop of lignite north of the Trang River improves in depth, but contains much pyrites and is not free-burning. There is a total thickness of 10½ feet. On the east coast attempts have also been made to work lignite a few miles south of Ban Sum on Klong Sinla.

Coal in Japan.—Some interesting particulars of the mining industry of Japan are given by Paul Jordan.‡ Of the Japanese mineral products coal takes the first place. In 1895 the output amounted to 4,772,656 tons. The coal is of Secondary or Tertiary age. It is met with in two principal districts, one in the Island of Hokkaido and the other in the island of Kiushiu. The latter coal-field yields 87 per cent. of the total production. The Takashima coal is the best in Japan. It contains 1·80 per cent. of water, 56·40 per cent. of fixed carbon, 35·50 per cent. of volatile constituents, 6·35 per cent. of ash, and 0·72 per cent. of sulphur. The exports of Japanese coal in 1895 amounted to 1,844,815 tons.

The production of coal in Japan§ has increased from two million tons in 1888 to about six million tons in 1897, and the exports

* *Bulletin Technologique*, 1898, pp. 931-998.

† "Five Years in Siam," vol. ii. pp. 2, 13, 80, 81. London, John Murray, 1898.

‡ *Annales des Mines*, vol. xiv. pp. 530-556.

§ *Iron and Coal Trades Review*, vol. lviii. pp. 19-20, with plate.

have increased from under one million to two and a half million tons in the same period. The more important coalfields are those of Miike, Takashima, Hizen, Amakusa, Chikuho, in Kiushiu; Atsusa, Kishiu, Shiramigu, and Aburato, in Houshiu; and Ishikari, Yubari, Horonai, Sorachi, in Hokkaido. There are other smaller coalfields that have been but imperfectly explored.

One of the largest and the most productive of the Japanese coalfields is that of Miike, in the island of Kiushiu, 33° N. lat. and 130° E. long. It has a proved area of about 25 square miles, and is the exclusive property of Mitsui & Co.

Several seams of coal occur in the Miike coalfield, but the first and the second seams only are capable of being economically worked. The first seam averages 8 feet in thickness of solid coal, without any interstratified band of shale, as is frequently found in most of the Japan coal-seams. This seam is remarkably uniform in quality and thickness, the thickest part often reaching a thickness of over 20 feet of pure coal. The second seam lies only from 6 to 10 feet below the first seam, its thickness being about 6 feet, but at present it is being worked only on a limited scale for local consumption.

On account of its calorific power, the Miike coal was soon recognised by economic users of steam as a standard coal in the Asiatic markets, in spite of having a rather unfavourable appearance.

W. Smith gives the following analyses of the coal:—

| Carbon. | Hydrogen. | Nitrogen. | Sulphur. | Moisture. |
|---------|-----------|-----------|----------|-----------|
| 75.22 | 5.84 | 1.11 | 3.15 | 0.62 |
| 74.88 | 5.91 | ... | 3.13 | 0.65 |

There are four collieries now working, and the output for last year is expected to reach a million tons. Much trouble from water had to be overcome in sinking. In 1882 the Oura mine was sunk to a depth of 240 feet, the Nanoura shaft was completed in 1883, and the Myanoura shaft in 1887. In 1883 an incendiary fire caused much loss of life, and the great earthquake of 1889 caused some of the mines to be drowned, so that a large Hawthorn-Davy differential pumping engine had to be procured and set to work.

The 8-foot seam is remarkably uniform in quality and thickness over a very large area. Up to the present, the mines in this seam are extraordinarily free from explosive gases, so that naked lights are invariably used. The second seam lies only from 6 to 10 feet below the first seam, and its thickness averages 6 feet near the outcrop, but it is more irregular and uncertain in the deeper portions. The coal from the second seam is free-burning and non-caking, but

its quality is inferior to the coal from the 8-foot seam, and it is now worked only on a limited scale for local consumption. The strata overlying the coal are composed of different kinds of sandstone, more or less coarse, porous, and fissured, which allow an easy passage of water from the surface to the coal-seam, thus rendering the process of mining expensive and dangerous from flooding. But, on the other hand, the dip is comparatively gentle (about 5°), the roof is firm and strong, and no faults worth consideration are found.

In the Nanoura mine the rooms average 15 feet in width and 8 feet or more in height. The coal is mined by the pillar-and-stall system, the pillars being 66 feet square. As far as practicable, the levels are driven in the direction of the strike from either side of the engine incline at convenient distances from 500 to 700 feet apart. The engine incline is parallel with the dip, and is 3000 feet in length. The underground workings cover an area of 437 acres, but two-thirds of the coal is left as pillars. The bulk of the mining is done by convicts, about 1500 men being employed. Illustrations of the plant, coal-cleaning apparatus, and shipping arrangements are appended.

III.—CHARCOAL.

Heating Power of Wood.—It has hitherto been thought that hard woods give more heat than soft woods. This is true for equal volumes, but not for equal weights. A table has been published* in which the lime is taken as the standard, showing that the available heat is as follows :—

| | |
|-----------------------|------|
| Lime | 1.00 |
| Fir | 0.99 |
| Elm | 0.98 |
| Pine | 0.98 |
| Willow | 0.97 |
| Chestnut | 0.97 |
| Larch | 0.97 |
| Maple | 0.96 |
| White deal | 0.96 |
| Poplar | 0.95 |
| Alder | 0.94 |
| Birch | 0.94 |
| Oak | 0.91 |
| Acacia | 0.91 |
| White beech | 0.91 |
| Red beech | 0.90 |

* *Revue Scientifique*, vol. xi. p. 766.

It appears from these results that certain soft woods, such as fir, have greater heating power than hard woods, such as oak and beech.

Peat Charcoal.—According to Holtz,* at Oldenburg, in Germany, peat (cut by Dolberg turf-cutters from a large moss adjacent to the Hunte-Ems Canal) is converted into coke by the Ziegler-Stiemer process, the retorts used being similar to those employed in the distillation of brown coal, vertical cylinders about 8 yards in height and 2 yards in internal diameter, the lower two-thirds being formed of glazed firebrick and the remainder of cast-iron rings, space being afforded about half way up for the discharge of the gaseous products. The dried peat is fed through the top, and the glowing coke drawn off at the bottom into a chamber, where it is quenched by a steam jet. A light or a heavy coke is obtained according to the quality of the peat and the heat of the retort, a high temperature favouring the production of a dense coke resembling that from ordinary coal. When mixed with nitre, the light coke replaces charcoal briquettes, whilst the heavier quality is used in copper-works and blast-furnaces, for which purposes it is well adapted, being free from sulphur and phosphorus, burning quietly, and giving out about 7000 units of heat.

The vapours liberated in the still are condensed, the permanent gases being employed to heat the furnaces. The tar is redistilled and yields benzol, a heavy gas-oil, and a solid product, furnishing paraffin and lubricating oil, the residue varying from a viscous pitch to hard carbon suitable for the manufacture of arc-lamp pencils. Calcium acetate and ammonium sulphate are recovered from the tar-water. From 8 to 10 tons of peat can be coked in each retort per diem, furnishing 36 per cent. of coke, 3 per cent. of tar, 20 per cent. of tar-water, 21 per cent. of moisture, and 20 per cent. of gas; the tar-water yielding 20 kilogrammes of ammonium sulphate, 30 kilogrammes of calcium acetate, and about 10 kilogrammes of methyl alcohol per cubic metre.

IV.—COKE.

Natural Coke.—A discovery of natural coke is reported from Gendesse Valley, Plumas county, Colorado. Some 15 feet thick of coal has been converted into natural coke. A test of 1000 lbs. of this

* *Engineering and Mining Journal*, vol. lxxvi. p. 756.

material at the Greenville Foundry showed that it possessed excellent heating qualities. It should, therefore, facilitate the development of the metal mines in that isolated region.*

The Coking of Non-Caking Coals.—O. Simmersbach† observes that when various coals are watched during the coking process, it will be noticed that coking coals swell up much more than the gas and anthracitic coals. The author now deals with the use of pressure in endeavouring to produce from the two latter kinds of coal a good compact coke. The first attempts were made to do this in the coke-oven itself.

Thus at the Friedrich-Orze colliery in Upper Silesia, heavy plates were placed on the coal in the coke-oven, and these were allowed to rest on the charge during the coking process. At Borsigwerk the coal after charging was rolled in the oven. C. Sachse subsequently employed stamping. None of these processes has, however, been adopted in practice, and similar efforts have also proved useless. Other attempts have been made to produce satisfactory results by compressing the coal before charging, and with greater success. The author describes and illustrates a number of such methods.

The Requirements of a Good Coke.—In an exhaustive article on the chemical principles involved in the manufacture of coke, O. Simmersbach ‡ shows that the points which should be insisted on in a good coke for metallurgical purposes are :—(1) Not over 4 per cent. of water ; (2) not over 9 per cent. of ash ; (3) not over 1 per cent. of sulphur ; (4) not over 0·18 per cent. of phosphorus ; (5) not over 6 per cent. of fine coke in any shipment ; (6) a crushing strength of at least 1140 lbs. per square inch.

The Use of Coke-Oven Gas for Illuminating Purposes.—The use of coke-oven gas for illuminating purposes is considered in *Stahl und Eisen* § and by C. Schmidt. || This, it is pointed out, has been already shown to be not only possible, but that the use of a coke-oven instead of the customary retorts for the production of illuminating gas actually presents advantages. Wages are less, for instance, as are also the repairs,

* *Colliery Guardian*, vol. lxxvi. p. 986.

† *Stahl und Eisen*, vol. xviii. pp. 1078-1084, five illustrations.

‡ *Revue Universelle des Mines*, vol. xlii. pp. 350-375 ; vol. xliii. pp. 181-195, 273-299 ; and vol. xliv. pp. 78-97.

§ Vol. xix. pp. 179-185.

|| *Journal für Gasbeleuchtung*, vol. xlii. pp. 241-246.

and much greater choice of coal is possible. Indeed, it is observed, it is wonderful that it has not already been introduced at large gas-making plants. With small ones the use of the coke-oven is not possible. All kinds of coke-ovens are not, it is true, suited for gas-making purposes. If, in the practical working of the coke-oven, a certain pressure is necessary in the flues, or air is certain to enter, the gas becomes poor, and in cases it may appear doubtful whether a subsequent carburisation would produce a gas of adequate illuminating power. The gas yielded by the furnace must of itself have an illuminating power of 6 or 8 candles if additional carburisation is to be profitable. The sale of coke-oven gas is only of recent occurrence. It is now done in Belgium, Lower Silesia, Westphalia, and elsewhere, and a large plant is in process of erection for lighting the town of Boston. In Westphalia the town of Castrop is lit entirely by coke-oven gas. At Boston four hundred coke-ovens are to be erected.

Nearly all coke-ovens where the by-products are collected fail to utilise the whole of the gas they make, an excess remaining which is nearly always utilised for heating boilers. It is necessary, therefore, to consider what is the value of the gas for this purpose, and what as an illuminant. Calculations are given which show that the gas is far more profitable when used for illuminating than it is when employed for heating, and this is more and more the case the larger is the available excess of gas from the coke-ovens. The coke-ovens must, however, be worked with much regularity, so as to yield a gas of a steady composition. If the gas is in itself too poor an illuminant, then it is useless to attempt to improve it by the addition of more benzol, as experience has shown that the excess of benzol so added simply separates out again. American progress in the use of this gas is then considered. In connection with this it is shown that in a coke-oven test the percentage of methane produced during the coking diminished steadily from the commencement of the process, at first slowly, and then quite rapidly towards the end of the coking process. With hydrogen the reverse is the case, as it shows an increase which, at first but slow, subsequently becomes rapid. The quantity of carbon monoxide formed is but slight, and is subject to great variations. The heavy hydrocarbons, with a percentage of about 6.5, remain approximately steady during the first few hours of the coking, and then gradually diminish towards the end of the process. The percentage of carbon dioxide remains at between 3 and 4 during the first twenty hours, and then diminishes gradually to about 1 per cent. The quantities of oxygen and nitrogen

in the gas are in part due to the coke-oven not being air-tight. The average percentage of nitrogen was at first about 7·7, subsequently increasing to 9·1, and increasing considerably towards the end of the process. This is due to the gas-pressure inside the oven being less towards the end of the coking, and the entrance of air into the oven consequently facilitated. The percentage of nitrogen may, under the best conditions, be reduced to about 5. The following are average analyses of the gas in the case referred to for (I.) the first fourteen hours forty-six minutes, and (II.) for the last nineteen hours ten minutes, an average analysis (III.) being also shown :—

| | I. | II. | III. |
|------------------------------|-----------|-----------|-----------|
| | Per Cent. | Per Cent. | Per Cent. |
| Heavy hydrocarbons | 5·2 | 2·4 | 3·8 |
| Methane | 38·7 | 29·2 | 33·9 |
| Hydrogen | 38·4 | 50·5 | 44·5 |
| Carbon monoxide | 6·1 | 6·3 | 6·2 |
| Carbon dioxide | 3·6 | 2·2 | 2·9 |
| Oxygen | 0·3 | 0·3 | 0·3 |
| Nitrogen | 7·7 | 9·1 | 8·4 |
| Totals | 100·0 | 100·0 | 100·0 |

The coal coked contained 75·1 per cent. of carbon, 3·75 per cent. of hydrogen, 5·84 per cent. of ash. As charged into the coke-oven it contains 9·9 per cent. of moisture. These experiments, a full account of the results of which is given, were made by F. Schniewind in one of a battery of thirty Otto-Hoffman coke-ovens.

In considering these experiments, *Stahl und Eisen* points out that it would not be readily practicable, as suggested, to divide the coking period into three stages, and to separate the gas produced in each of these, but that it would appear best to make two divisions, using the gas made in the earlier stages of the coking for illumination, and that made subsequently for heating purposes. The consumption of gas in a town is subject to great variations, but the yield of gas from a coke-oven is of a more constant character, and large additional quantities of gas cannot be made at any moment. To avoid this difficulty it is suggested that the coke-ovens themselves might be heated by producer gas. In this way the whole of the coke-oven gas would become available for utilisation for illuminating purposes, or any desired portion might be so utilised. If the whole of the coke-oven gas is utilised, then its average illuminating power sinks from 14·7 to 11·8 candle-power. Other methods are conceivable to enable a coke-oven plant to

suddenly make an increased quantity of gas. Thus the coal might not be completely coked, a product suitable for use in stoves being left. The method adopted must, however, depend on local circumstances.

The Theisen By-product Process.—F. Simmersbach * describes the Theisen process for the purification of works gases and the collection of by-products from coke-ovens.

The separation of dust and vapour constituents from blast-furnace gases by simple settlement is impossible, owing to the large quantities of gas that have to be dealt with. Theisen has patented a centrifugal process, in which this separation is effected by subjecting the gas to an intimate treatment with water in a centrifugal separator, an exhaust being employed. A satisfactory separation is stated to result.

In the case of coke-oven plants, by using such a centrifugal separator, a much more perfect separation of the tar results than takes place when ordinary methods are employed, while the use of gas-coolers becomes unnecessary. So complete, indeed, is the separation of the tar, that analysis fails to show its presence in the gases that escape from the centrifugal apparatus, while the tar obtained is almost anhydrous. The apparatus can be erected in the immediate vicinity of the coke-oven plant, and its dimensions are so small that the question of space need scarcely be considered. After leaving the tar separator the gases pass to another one, in which they are treated with water for the separation of the ammonia. The benzol is collected by a similar washing arrangement, oils replacing the water used in the case of ammonia. The mode of distillation of the various liquors and the tar is described, and the apparatus itself is illustrated, elevations and plans being given. The author mentions various advantages which the process is stated to possess, as compared with the methods usually employed, the first cost and subsequent up-keep, amongst other points, being considerably less.

Other illustrations have appeared † of Theisen's apparatus for purifying blast-furnace gas and for collecting coke-oven by-products. A plan of the plant for a coke-oven plant with sixty ovens is given.

Improvements in the Coking Process.—L. Rürup ‡ describes an appliance designed by J. Quaglio for stamping in the coal

* *Stahl und Eisen*, vol. xix. pp. 57-60; two illustrations.

† *Iron and Coal Trades Review*, vol. lviii. p. 187.

‡ *Chemiker Zeitung*, vol. xxiii. pp. 160-161.

charged into coke-ovens, and also another charging arrangement patented by the Röchling Ironworks at Völklingen, on the Saar. A modified coke-oven also described is that of F. J. Collin, in which arrangements are made for ensuring a high temperature at points where, as a rule, this does not exist in ordinary coke-ovens. The channels, too, are more readily supervised. Another new coke-oven is that patented by J. W. Neinhaus. This is a horizontal oven, with channel arrangements modified in such a way as is anticipated will lead to a more even temperature in the coke-oven. The Balmke Works in Westphalia is also erecting a horizontal coke-oven of new design. This modification again consists in a variation of the gas channel arrangements.

The utilisation of the waste heat from coke-ovens at the Ferfay mines, Pas-de-Calais, is discussed by Souлары.*

The Manufacture of Coke.—In a series of articles F. C. Keighley† deals with the manufacture of coke. Amongst other points the time of coking is discussed, and 24-hour coke is advocated. The influence of the kind of coal, and of the form of oven and its age on the yield are dealt with, many tables being given. Next the wear and tear of ovens are dealt with at considerable length, and an account is given of the repairs necessary in working a plant of beehive ovens. The method of running the plant, book-keeping, and the staff are other subjects upon which comments are made. To aid in the regulation of the output a table is given, showing the coal charged in bushels and tons, and the yield in tons for 60, 66, and 70 per cent.

R. M. Atwater‡ offers some observations on the manufacture of coke for domestic purposes, and of briquettes from soft Ohio coals and slack. Incidentally reference is made to the reduction of the percentage of sulphur in coals carrying a large amount of that element by fine grinding and washing.

Beehive Ovens.—The coking in beehive ovens of the coals of the New River District, West Virginia, is dealt with by C. Catlett.§ Coal from the Sewell seam averages: Moisture, 0·73; volatile matter, 26·43; fixed carbon, 70·04; ash, 2·46; sulphur, 0·56. The coke of the district

* *Bulletin de la Société de l'Industrie Minérale*, vol. xii. pp. 343-379.

† *American Manufacturer*, vol. lxiii. pp. 808, 843, 877, 914, 952; vol. lxiv. pp. 14, 37, 61, 81, 105, 129, 157, 196, 217, 237, 256.

‡ Paper read before the Ohio Institute of Mining Engineers, January 1899.

§ *Transactions of the American Institute of Mining Engineers*, New York Meeting, 1899.

is made from slack coal, but, in spite of this, the coke usually contains only about 6 per cent. ash. The sulphur, while variable, is usually low, running from 0·50 to 0·60 per cent. A coal of the average composition would theoretically furnish about 75 per cent. of coke. As a matter of fact, the majority of the ovens in the district do not yield 60 per cent., and many of them run less than 55 per cent.

Most of the ovens are 12 feet in diameter and 6·5 feet high on the inside. All the ovens are provided with draft-boxes, placed on either side of the door, and slightly deflected where they enter the oven, so as to be at right angles to the axis on which the oven is constructed. Where the draft enters the oven the hole is 4 inches high by 7 inches wide, and the bottom of the opening is 4 feet from the floor of the oven. A large number of observations were made of the burning of a set of eight ovens by means of the draft-boxes, extending over a period of about two weeks. The results are given in detail in a series of tables. At the time of the observations the ovens were working on 72-hour and 96-hour coke. The charges for 72-hour coke averaged 10,640 lbs., and for 96-hour coke 11,312 lbs.

A series of articles have recently appeared,* dealing with the use and manufacture of coke in the iron industries. The various forms of ovens are described, and particulars are given of their performances and products.

Coke-Oven Appliances.—Illustrations have appeared † of Buchanan's ram or pusher for discharging coke-ovens at a works at Widnes, and also Littleboy's design of a crane for lifting the doors and doing other work on the ovens.

Various machines have been proposed for compressing the coal in coke-ovens in order to facilitate the coking of inferior coals. Illustrations of a number of these machines have appeared,‡ including those devised by Röchling, Hoffmann, Brinckard, Hübner, Klein, and Kuhn.

An illustration of a coke-oven lorry equipped with an electric motor for its propulsion has appeared.§

The Coppée Coke-Oven.—The most recent form of the Coppée coke-oven is considered in some detail.|| By its use even poorly

* *Colliery Guardian*, vol. lxxvi. pp. 387, 469, 559, 649, 753, 833.

† *Ibid.*, vol. lxxvi. pp. 557-558.

‡ *Iron and Coal Trades Review*, vol. lvii. pp. 1039-1040; vol. lviii. p. 101.

§ *Mines and Minerals*, vol. xix. p. 229.

|| *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlvii. pp. 17-19.

coking coal is stated to be capable of employment, the yield at the same time being high, and the coke of excellent quality. The air used for the combustion of the gas in these ovens is pre-heated by contact with the brickwork of the oven.

The Bauer Coke-Oven.—J. Elsner* points out that F. Simmersbach has observed that the maximum annual yield of a German coke-oven working direct—without condensation, that is—amounts to a thousand tons, the coke-oven which does this being specially described, and the statement is added to the description that this oven has up to now been the one with the highest output. The author states, however, that this assumption is incorrect, as the battery of eight ovens on the new Von Bauer system which have been working for some time at the Hannover Colliery have given better results. This system of coke-ovens was patented in 1893 and 1894, and the first battery of eight ovens was laid down at Shaft No. III. of the Hannover Colliery belonging to F. Krupp. The original ovens were of 6-ton capacity, but these were subsequently enlarged, and the enlarged ovens were put in operation towards the end of 1897, since which time they have continued at work without any interruption. The author describes these ovens in considerable detail, and with the aid of numerous illustrations. He points out that this type of oven may at any time be used as an ordinary direct-coking oven, or as an oven arranged for the collection of the by-products, or it may be utilised for a mixed process. The Bauer coke-oven takes a charge of from 9 to 10 tons of coal, which it cokes in from 30 to 36 hours, and while occupying less space than ordinary coke-ovens, it is also less expensive to work in practice. In form the oven is a modified Coppée oven. In the case specially considered, the battery of eight coke-ovens takes a charge of 9 tons in each oven. The coal contains 12 per cent. of moisture, and yields as a maximum 68 per cent. of coke when coked in the ovens previously employed. In the Bauer oven the average for a whole year was 73·24 per cent. The larger ovens will have a 30-hour coking period. This corresponds with an annual out-turn of 1898 tons. The yield of 73 per cent. above referred to was an excess of 4 per cent. as compared with crucible assays of the same coal.

The results obtained with the Bauer coke-ovens erected at the Hannover Colliery at Hordel have been published.† Eight experi-

* *Stahl und Eisen*, vol. xix. pp. 361-366; thirteen illustrations.

† *Glückauf*, vol. xxxv. pp. 85-87, 202-204.

mental ovens were put up 1897, at a cost of £450 each. The results have proved very satisfactory, the average yield of coke being 73·24 per cent., whilst the yield in the ovens formerly employed was 69 per cent.

The Otto-Hoffman Coke-Oven.—W. L. Affelder * describes the Otto-Hoffman coke-ovens and by-product apparatus of the Pittsburg Gas and Coal Company. The plant comprises 120 coke-ovens. The yield of coke amounts to 75 to 78 per cent. of the coal charged. The yield of tar is 5 to 6 per cent., that of ammonium sulphate 1·25 to 1·45 per cent., and that of gas 10,000 cubic feet per ton of coal. Eight men in two shifts of twelve hours each are employed, and the total coal consumption is 600 to 700 tons per day.

The Semet-Solvay Coke-Oven.—W. H. Blauvelt † describes the Semet-Solvay coke-oven plant erected at Ensley, Alabama, for supplying the blast-furnaces. The plant consists of 120 ovens arranged in two parallel blocks of 60 each. About 420 to 460 tons of coke is expected to be made daily from washed slack from the Pratt seam. Coal is delivered from 30-ton railway waggons into hopper bins holding 1500 tons, from which it is withdrawn below for charging into the ovens. The coke is pushed out of the oven by a ram on to a truck, which is 30 feet long and 7 feet in width, on which it is quenched. By a wire rope and winding engine the quenching cars are drawn up a grade of 1 to 6 into the stockhouse, to an elevation sufficient to permit the coke to be dumped into a large bin with a sloping bottom, which in turn discharges directly into the furnace buggies that are sent to the tunnel-head. Thus the coke is moved but three times after it is quenched until it lies in the furnace, and the breakage is reduced to a minimum. The by-product building is located midway between the two blocks of ovens, and is of slow-burning mill construction. Two sets of gas condensers, one for each thirty ovens, are at each end of the building, and beyond them at one end is the sulphate of ammonia house. The surplus gas from the plant, of which there will be some 2,000,000 cubic feet or more per day, is to be used in the new basic open-hearth steel-mill that is being erected within a short distance of the oven plant.

* *Mines and Minerals*, vol. xix. p. 318.

† *Transactions of the American Institute of Mining Engineers*, Buffalo Meeting, 1898 (advance proof).

Illustrations of the by-product ovens started in December last at Benwood, West Virginia, have appeared.*

V.—LIQUID FUEL.

The Origin of Petroleum.—A. F. Stahl † observes that his own observations have not been in accord with the various theories that have hitherto been suggested as to the origin of petroleum. Passing over Berthelot's and Mendeleeff's theories, he considers those of C. Engler and C. Ochsenius to be nearest the truth, though too complicated to be exactly what has happened in nature. Great catastrophes are unnecessary to effect the formation of petroleum, and he has found no trace of such in the petroleum-bearing strata that he has examined. The formation in which petroleum is found in the Caucasus, in Transcaspia, the Ural Steppes, and Persia is always Tertiary. The bedding is usually very little disturbed, and volcanic action has been purely local. The killing of animals by strong salt solutions in the past he considers quite improbable, for he thinks that the formation of these strong salt solutions and of the salt-beds took place either after and not before the formation of petroleum, or, and that usually, at the same time. The Cretaceous and Jurassic limestones underlying the Tertiary beds contain no salt deposits that the author thinks would bear upon the case. No bones, teeth, or other similar organic remains are met with in the naphtha-bearing beds, and these would undoubtedly be found if the petroleum was due to the killing off of large numbers of animals by these brine solutions. The author considers that it is not to animal life that the origin of petroleum is to be attributed, but to diatoms. The geological formation in which the petroleum is found points to conditions under which such diatom life would have been prolific, such as low marshy or flooded lands, by the side of a sea or salt lakes, accompanied by changes of level as time went on.

Petroleum in Italy.—T. Taramelli ‡ describes the occurrence of petroleum at Salsomaggiore in the Parmese Apennines. The strata yield oil in abundance, and the stratigraphical conditions are such as to indicate that satisfactory results would attend a systematic exploration of the district.

* *Iron Trade Review*, December 15, 1898, pp. 8-9.

† *Chemiker Zeitung*, vol. xxiii. p. 144.

‡ *Rendiconti del Reale Istituto Lombardo*, vol. xxx. pp. 786-996.

Petroleum in Alsace.—Boring for petroleum is in progress at Sundgau, in Southern Alsace,* with promising results. The oil industry of Lower Alsace continues to make progress, the output having increased from 576 tons in 1876 to 22,000 tons in 1897. At the present time the industry affords employment to 600 persons.

Petroleum in Bukowina.—Emil von Habdank-Dunikowski † describes the occurrence of petroleum in the Duchy of Bukowina. The oil-field is one of great richness, as yet hardly touched. There is good railway communication and an ample supply of cheap wood for fuel.

Russian Petroleum.—The petroleum deposits in the deltas of the Rivers Sagis and Emba in the Ural are described by A. F. Stahl.‡ The delta of these rivers covers an area of about 15,000 square miles to the east of the entrance of the Ural River into the Caspian Sea. In this district springs of oil and brine are met with, as well as asphaltic deposits, and these the author considers.

A. F. Stahl§ states that petroleum has been found near the village of Woznesensk, in the Northern Caucasus, about 40 miles to the north of Wladikawkas and 16 miles south of Mosdok. To the north of the great range of the Caucasus are several other low ranges of hills running parallel with the great chain. They reach to a height of about 2000 feet above sea-level. Near Wladikawkas are two such ranges, and these contain petroleum springs. The formation is considered from a geological standpoint, and it is stated that beds of calcareous marl, clays, clay slates, schists, and sandstones are met with. Five springs of petroleum occur within a distance of four miles of each other. The oil occurs mixed with brine, and sulphuretted hydrogen is also evolved. The petroleum has a specific gravity of 0·925, and is dark brown in colour. Small quantities of gas also escape. Asphalt is not met with in the neighbourhood. No boreholes have yet been put down.

An elaborate investigation|| of the illuminating value of Russian petroleum has been carried out by M. Albrecht. The flash-point of Russian oil is, he finds, 5° to 7° C. higher than that of American oil.

* *Der Gnom*, vol. i. No. 20.

† *Ungarische Montan Zeitung*, vol. v. No. 1.

‡ *Chemiker Zeitung*, vol. xxiii. p. 22. § *Ibid.*, p. 161.

|| *Mining Journal*, vol. lxxviii. p. 1329.

It contains more pure illuminating oil and less heavy oil, and for the same illuminating effect the oil consumption is 14 per cent. less.

Sir Marcus Samuel* discusses the production, supply, and uses of liquid fuel; and F. Thiess† gives particulars of the production of petroleum in Transcaspia.

Petroleum in Ohio.—The latest oil-field in America to attract attention is in the neighbourhood of Scio in Ohio. The oil is not equal in quality to some of the oils of Pennsylvania and West Virginia, but the difference is not great enough to make a distinction in the market price. The field will, it is thought, prove lasting territory, and drilling is easy. The average depth from the surface of the Berea grit, in which the oil is found, is 1200 feet.‡

Petroleum in West Virginia.—A map of West Virginia has been compiled and published by Russell L. Morris for the West Virginia Geological and Economic Survey. It shows the oil and gas wells and the New River, Allegheny, and Pittsburg coal area.

Grahamite.—I. C. White§ discusses the origin of grahamite in Ritchie county, West Virginia. It is a black mineral resembling the albertite of Nova Scotia, and contains 79 per cent. of carbon, $6\frac{1}{2}$ of hydrogen, and 14 of oxygen. It is found in a fissure which in parts is five feet in width. At one time it was mined for fuel. Oil is found in close proximity; and it is suggested that the grahamite is due to products of oxidation of the oil.

Bitumen from Portuguese West Africa.—J. P. Gomes|| has examined specimens from a supposed coal deposit in the province of Angola, and finds that the mineral is not coal, but is a new bitumen having close affinities to albertite. Analysis shows it to contain—

| Hydrogen. | Oxygen. | Nitrogen. | Carbon. | Residue. |
|-----------|---------|-----------|---------|----------|
| 7.83 | 8.80 | 1.71 | 74.74 | 6.92 |

The author proposes for the new bitumen the name of "libollite," Libollo being the locality where it occurs.

* *Journal of the Society of Arts*, vol. xlvii. pp. 384-393.

† *Zeitschrift für das Berg-, Hütten- und Salinenwesen im preussischen Staate*, vol. xlvii. pp. 133-134.

‡ *American Manufacturer*, vol. lxiv. p. 125.

§ Paper read before the Geological Society of America, December 1898.

|| *Comunicações da Direcção dos Trabalhos geologicos de Portugal*, vol. iii. pp. 244-250, 290-291.

VI.—*NATURAL GAS.*

The Composition of Natural Gas.—The constancy of composition of natural gas is a question of practical importance to manufacturers, and as the opinion has frequently been expressed that natural gas fluctuates in its heating power, F. C. Phillips* has investigated the subject. The results of duplicate determinations of nitrogen in the same sample of gas were closely concordant, the variations not exceeding in any case 0.03 per cent. Since, however, samples of gas from the same well, collected at different times, showed variations of nearly 2 per cent., it would appear that fluctuations in the composition of natural gas do really occur. Thus, natural gas is composed mainly of the hydrocarbons of the paraffin series associated with very small quantities of nitrogen, carbonic anhydride, and water vapour. Olefines, represented by ethylenes, are sometimes found in minute proportions, together with traces of organic sulphur compounds in some instances. Free hydrogen, carbon monoxide, hydrogen sulphide, and oxygen do not occur. For the purpose of studying the fluctuations in the composition of natural gas, the nitrogen or incombustible residue was selected for determination. The apparatus used and the precautions taken are fully described. In samples taken during one year from one of the Pittsburg wells, the nitrogen varied between 1.2 and 3.2 per cent. The bearing of the experiments, which are not yet concluded, on the condition in which the gas exists in the rock are discussed.

Natural Gas in Indiana.—The natural gas supply of Indiana has diminished to such an extent that its early exhaustion is imminent unless steps are taken to reduce the consumption. The question is again coming up, therefore, as to whether the piping of gas outside the State cannot be stopped.†

Natural Gas in Kansas.—E. Orton‡ describes the Iola gas-field in the south-east of Kansas. The gas is found in a sandstone of the Cherokee shales near the bottom of the Coal Measures, over an area of about three by seven miles. The top of the gas rock is on the average

* *Proceedings of the Engineers' Society of Western Pennsylvania*, vol. xiv. pp. 290-307.

† *Iron Age*, vol. lxiii. February 16, p. 10.

‡ Paper read before the Geological Society of America, December 1898.

131 feet above tide level, and never more than 176 feet. At the summit the largest well is situated, and its production amounts to ten million cubic feet daily.

VII.—ARTIFICIAL GAS.

Water-Gas.—A short history of water-gas has recently appeared,* in which its invention is ascribed to Felice Fontana, an Italian chemist, who died at the beginning of this century. English users are not mentioned, but several European users are referred to, and a list is given of plants using the Dellwik producer.

VIII.—COAL-MINING.

Deep Boring.—Some illustrations of borings and a further description of the Davis calyx drill have recently appeared.†

A. Lukaszewski ‡ describes various recent improvements in deep boring. These include the Raky and the Wolski and Odrzywolski under-reamer for enlarging boreholes, both of which are illustrated and described at some length.

T. Tecklenburg § describes the apparatus of Fieseler and Schultheis for raising lining tubes; and Fauck || deals with a percussive drill yielding cores.

Shaft-Sinking.—A. H. Leech ¶ gives an account of the Maypole Colliery sinking, Wigan, and describes the heavily watered ground, the pumps, and the lining. Reference is made to J. Keen's ** description of this sinking.

Further particulars of the sinking at the Dover Colliery have appeared in a report by N. R. Griffith. †† Owing to the large amount of

* *Polytechnisches Centralblatt*, through the *Iron and Coal Trades Review*, vol. lvii. p. 1142.

† *Engineering*, vol. lxvi. pp. 776-778.

‡ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlvii. pp. 1-4; four illustrations.

§ *Berg- und Hüttenmännische Zeitung*, vol. lvii. p. 445.

|| *Ibid.*, vol. lvii. p. 447.

¶ *Journal of the British Society of Mining Students*, vol. xxi. pp. 57-71.

** *Journal of the Iron and Steel Institute*, 1898, No. II. p. 429.

†† *Colliery Guardian*, vol. lxxvi. p. 843.

silt and sand pumped with the water in No. 1 pit, the sides began to come in, so the pumps were partly withdrawn and the shaft filled with beach shingle until the two other shafts progressed sufficiently to aid the drainage.

The sinking of shafts through quicksand at Bascoup Colliery, Belgium, is described by E. Briart.*

An account of a sinking completed last year at the Victor Colliery, Westphalia, has appeared.† Owing to the water encountered, the Kind-Chaudron method of boring and tubbing was adopted, but for various reasons a good joint was not obtained at the moss-box. The operations that were undertaken to remedy this state of affairs are described.

A method of winding while deepening a shaft‡ at the Emscher Colliery at Altenessen, Germany, has been illustrated. A truck is suspended below the cage for lifting the spoil to an upper level, where it is removed and stored until it can be wound to the surface.

The operations of sinking the Hugo shaft near Holten are described by Selbach.§ A sinking shoe and cast iron tubbing was used, but the tubbing failed and the shaft was lost.

J. Kohout|| describes the method adopted for deepening the Ignaz shaft at Illgoth, in Moravian Ostrau. Instead of provisionally lining the shaft with timber, brickwork was put in at once in sections of 4 to 7 yards as the sinking proceeded. This method, which had not previously been used in the Karwin coalfield, leads to economy in time, labour, and cost of material, and seems to present greater security for circular shafts.

Winding Appliances.—F. Kesteven¶ describes the wire-rope conductors and receiving-rods at the top and bottom of the down-cast shaft of the Monckton Main Colliery, near Barnsley. There are six conductors, three on each side of the shaft, which is nearly 500 yards deep. The advantage obtained in placing them as stated is that it keeps the centre of the shaft clear in case of anything falling down the shaft. The cages run very steadily, and are free from oscillation.

* *Revue Universelle des Mines*, vol. xlv. pp. 238-256.

† *Colliery Guardian*, vol. lxxvii. pp. 292-294.

‡ *Glückauf*, vol. xxxv. pp. 201-202.

§ *Zeitschrift für Berg-, Hütten- und Salinenwesen im preussischen Staate*, vol. xlvii. pp. 78-88.

|| *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlvi. pp. 737-741.

¶ *Journal of the British Society of Mining Students*, vol. xxi. pp. 85-86; one plate.

Perroy* describes the construction of some winding-drums with tangential spokes, recently erected at the Saint Amédée Colliery.

W. Freakley† expresses the opinion that it is not advantageous to use compound-engines for winding purposes.

Illustrations have appeared‡ of electrically-driven winding or hauling-engines for underground use.

An illustration has appeared§ of a winding-engine for the Maxwell Colliery, Pennsylvania. It has conical drums 10 to 13 feet in diameter, driven by two cylinders 30 by 48 inches, using steam at 100 lbs. pressure.

W. G. Wilkins|| describes various labour-saving methods for raising and handling coal at the colliery. Amongst these is the method of emptying the tubs into a self-emptying cage, so as to avoid winding the tubs. This is only suitable for hard coal. The Ramsay caging apparatus is also described, and also other means for handling the full and the empty tubs at the surface.

The up-cast air-shaft fitted for winding with 12-decked cages at the Marchienne Colliery, Charleroi, Belgium, is described by Ghysen.¶

Leybold** describes a winding rope counterpoise which has been in use for some years at the Camphausen Colliery, near Saarbrücken.

Illustrations are given†† of devices for cleansing and lubricating winding-ropes. In Oppl's apparatus the rope passes through a conical vessel containing oil, and provided with brushing appliances above and below.

Details are published by Tomson‡‡ of various shafts at collieries in the Dortmund district, with their winding-plants. The deepest of these shafts is to be about 3280 feet in depth. The arrangements of the shafts are described, and then the winding-plants themselves are considered in detail.

Steel Head Frames.—Among the most interesting examples of the rapid extension of the use of steel in construction is its employment

* *Comptes Rendus Mensuels de la Société de l'Industrie Minière*, 1898, pp. 196-202.

† *Transactions of the Institution of Mining Engineers*, vol. xvi. pp. 427-428.

‡ *Iron and Coal Trades Review*, vol. lviii. p. 199.

§ *Engineering and Mining Journal*, vol. lvi. p. 491.

|| Paper read before the Ohio Society of Mining Engineers.

¶ *Revue Universelle des Mines*, vol. xlv. pp. 10-19. See also *Journal of the Iron and Steel Institute*, 1894, No. 11. pp. 253-255.

** *Zeitschrift für das Berg-, Hütten- und Salinenwesen im preussischen Staate*, vol. xlvii. pp. 68-72.

†† *Iron and Coal Trades Review*, vol. lvii. p. 686; vol. lviii. p. 111.

‡‡ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlvi. pp. 468-471; eight illustrations.

in the erection of head frames for mine shafts, which were formerly made of heavy timber framing. The most recent practice is exemplified in a steel head frame built at the new shaft of the Philadelphia and Reading Coal and Iron Company at Gilberton, Pennsylvania, illustrations of which have been published.*

According to W. L. Cowles, the shaft is 1100 feet in depth, divided into four compartments. The two compartments nearest to the engines are used for raising water, and are served by the engine nearest to the shaft, while the other two are ordinarily used for hoisting coal and rock, although in case of emergency they can also be used for water. The special arrangement of the shaft renders it necessary to place the sheaves serving the two front compartments, or those farthest from the engines, in front of and higher than the sheaves for the two rear compartments, and the engine operating the former must likewise be placed behind and higher than the engine operating the latter. Provision is made for a working load of 20 tons in each compartment of the shaft, and the engines have a capacity for raising these loads at a speed of 2300 feet per minute, the trip from bottom to top, therefore, lasting about half a minute. The rope is 2 inches in diameter, and is made of crucible steel wire. The sheaves are 14 feet in diameter, with 10-inch journals.

A number of illustrations of colliery head gears, past and present, have appeared in a series of articles on the subject.†

The Prevention of Over-Winding.—J. von Hauer ‡ illustrates the Oberegger safety catch, which is one of the cam type, thrown into action by breakage of the winding-rope.

Amongst the exhibits at the Auckland Industrial and Mining Exhibition is the Jacobsen-Rahe safety cage grip. § The cage is constructed on similar lines to the ordinary safety appliances, but if the cage should break away, it is instantly gripped both at the bonnet and bottom, whilst in addition to that there is a false bottom set in on springs, so that when the cage falls no concussion is felt.

Winding Ropes.—K. Habermann || considers the statistics relating to the replacement of winding ropes at the mines in the Breslau dis-

* *Engineering News*, vol. xl. p. 292.

† *Iron and Coal Trades Review*, vol. lviii. pp. 683, 861.

‡ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlvi. pp. 567-568.

§ *Mining Journal*, vol. lxix. p. 123.

|| *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlvi. pp. 513-515.

trict in the year 1897. The total number of such ropes replaced during the year was 164. Of these, three had broken suddenly. Since 1887 the number of such ropes that have been replaced has varied annually from a minimum of 92 in 1889 to a maximum of 164 in 1897. The number of ropes that broke suddenly in any year has never exceeded four during this period, nor been less than one. In earlier years the fractures were far more numerous, the improvement that has taken place of late being largely due to the fact that flat ropes are much less frequently employed now than was formerly the case. Crucible cast steel round ropes are those now usually employed in this district. Of the 164 ropes replaced in 1897, 156 were round and 8 flat. While the maximum length of life for one of these round ropes was 2646 days, in the case of the flat ropes it was only 631 days. The author considers that the question of the complete replacement of the flat rope by the round rope is now merely a question of time. In the case of the ropes referred to above, the maximum working effect of a flat rope was only 21,053 millions of metre-kilogrammes, while in the case of a round rope the working effect reached a maximum of 185,825 millions of metre-kilogrammes, or some $8\frac{1}{2}$ times as much as for the flat rope.

Signals Used in Mines.—Clements* deals with the various forms of signals used in mines, and especially with electric signalling. Particular attention is given to the conductors and other details.

W. E. Culbertson† describes an extensive arrangement of electric signals and telephones used for signalling to the engine-house from two shafts where seven seams are worked.

K. Dekanovsky‡ describes the electric signalling appliances for cages used at several collieries in Ostrau and at Brüx.

Shaft Fences.—V. Watteyne§ deals at some length with the means for preventing accidents in shafts, especially with the forms of the cages and their closing arrangements, and shaft fences.

J. von Hauer|| describes and illustrates the Lehinant arrangement

* Paper read before the South African Society of Electrical Engineers, through the *Engineering and Mining Journal*, vol. lxvi. p. 639.

† *Mines and Minerals*, vol. xix. pp. 351-352.

‡ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlvii. pp. 79-81.

§ *Annales des Mines de Belgique*, vol. iii. No. 4.

|| *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlvi. pp. 655-657; three illustrations.

for closing shafts, which is stated to have been introduced with success at several mines in the Brûix district.

Self-acting fences for staple pits and balance lifts are described by H. Michel and C. Lermusiaux.*

Various arrangements of shaft fences at German collieries are described and illustrated.†

Underground Haulage.—L. M. Evans ‡ compares the methods of underground haulage used in the anthracite mines of Pennsylvania, including electric, compressed air, rope, and steam locomotive haulage. The latter will go out of use. Costs of the other methods are given as 1·42, 1·50, and 2 to 3 cents per ton mile respectively.

Further details are given of the compressed-air locomotives, with a plan of the workings and illustrations of the locomotives and means for charging them. Some accounts of the expenses are appended.§

A. D. Smith|| gives some statistics on the number of mules employed in anthracite mines during the past ten years. In 1888 there were at work 12,571, and this increased to 16,425 in 1896, but fell again to 15,877 in 1897. The average number of tons of anthracite shipped per mule employed has steadily fallen from 3034 to 2622 tons.

B. S. Randolph ¶ describes the haulage on the inclines of the Consolidation Coal Company at Frostburg, Maryland. The inclines are laid out on an average incline of 4 per cent., which is barely sufficient for the empty tubs to drag the rope in-bye, so a short length of 10 per cent. is built at the head of the slope to give the tubs an impetus at starting. The hauling drum runs loose on the shaft, and is coupled to the engine by a clutch when hauling out the empty tubs. The maximum speeds are 800 feet per minute out-bye and 1400 feet in-bye.

An illustrated description of the compressed-air haulage plant at the Coal Brook Mines, near Carbondale, Pennsylvania, has been published.** A large compressed-air locomotive is used in the Wilson tunnel, and a smaller one in the new Wilson tunnel. Compared with the cost of mule haulage, there is with the large motor a daily saving of £8, 10s., and with the small motor a saving of £2, 19s., the total daily saving with the two motors being £11, 9s.

* *Société des Ingénieurs des Mines du Hainaut.*

† *Colliery Guardian*, vol. lxxvii. pp. 107-110.

‡ *Mines and Minerals*, vol. xix. pp. 156-157.

§ *Ibid.*, pp. 199-201.

|| *Engineering and Mining Journal*, vol. lxi. p. 611.

¶ *Mines and Minerals*, vol. xix. pp. 132-133.

** *Ibid.*, vol. xix. pp. 199-201.

At a colliery in the Essen district of Prussia,* the sleepers in roadways where haulage is effected by horses are covered with wide channel iron for protecting them from wear. The device has been found to answer admirably.

H. De Lachapelle† describes the arrangements at the St. Eloy Collieries, Puy-de-Dôme, for lowering the loaded tubs, two at a time, on a special carriage running on an underground incline 321 feet long, with a gradient ranging between 20° and 15°. The incline, except at the centre, is laid with three rails weighing 20 lbs. per yard, with a gauge of about 3½ feet. The incline truck is provided with a special arrangement of keys for holding on the tubs, which are run on and off at the ends instead of sideways.

R. Peele‡ discusses the advantages of compressed air as compared with steam and electricity for the transmission of power in mines.

Illustrations are given§ of seamless steel tubs pressed from a single steel sheet.

Electricity in Mines.—The uses, advantages, and defects of electric transmission of power in mines are discussed by P. Evans|| in relation to lighting, signalling, pumping, haulage, blasting, drilling and coal-cutting. The subject is also dealt with by W. B. Esson.¶

J. H. Whittaker** discusses the use of electricity in mines and iron works, and deals especially with the advantages of three-phase currents.

J. McGhie†† gives an illustrated description of some of the latest forms of electric locomotives, pumps, drills, and coal-cutting machines used for mining.

An illustration has appeared‡‡ of a new type of Jeffrey electric locomotive for mining and other use.

G. R. Wood§§ describes the power-house, the electrically driven

* *Zeitschrift für das Berg-, Hütten- und Salinenwesen im preussischen Staate*, vol. xlv. p. 118.

† *Comptes Rendus de la Société de l'Industrie Minérale*, 1898, pp. 147-150.

‡ *Mines and Minerals*, vol. xix. pp. 365-366.

§ *Iron and Coal Trades Review*, vol. lviii. pp. 379-380.

|| *Journal of the British Society of Mining Students*, vol. xxi. pp. 124-129.

¶ *Minutes of Proceedings of the Institution of Civil Engineers*, vol. cxxv. pp. 54-111.

** Paper read before the South Staffordshire Institute of Iron and Steel Works Managers, March 1899.

†† *Cassier's Magazine*, vol. xv. pp. 37-48.

‡‡ *Engineering and Mining Journal*, vol. lxvi. p. 731.

§§ *Mines and Minerals*, vol. xix. pp. 202-203.

coal-cutting machines, pumps, and other plant at West Newton, Pennsylvania.

Max Schmidt* gives a detailed description of the electric plant of the Silesian coal and coke works at Gottesberg. The paper is illustrated by sixteen dimensioned drawings.

A report has been prepared by Leproux† for the French Minister of Public Works on the precautions taken in Great Britain in dealing with electric appliances in fiery collieries.

Grübler‡ has published a plan of the central electrical power station erected at the Glückauf Mines, near Sondershausen, in Germany. The power-house is built in two bays, one of which contains the winding engine and the ventilating fan, the other containing the electrical plant. The fan is of the Rateau type, and is capable of delivering 84,720 cubic feet of air a minute against a water gauge of 3·93 inches. It is driven by a 85-horse-power three-phase motor, making 480 revolutions a minute. The other bay of the power-house contains the central electrical plant, which is in triplicate. Each set consists of a compound condensing engine working with steam at a pressure of 110 lbs. per square inch, and of 350 normal horse-power, coupled directly to the dynamos. The cylinder diameters are 19·65 and 30·85 inches, the stroke being 27·5 inches. The dynamo for each set is a three-phase machine of 327 kilowatts capacity, running at 125 revolutions per minute, and working at 500 volts. The armatures of the dynamos are 9·84 feet in diameter.

O. Lasche§ describes the arrangements that have been made at a colliery at Höntrop, near Bochum, for driving an underground pump by power electrically transmitted. In connection with his description he considers generally the question of the transmission of power by the aid of electricity and its subsequent utilisation.

A very full description is published by F. Holzner|| of the method of electric transmission of power adopted at the Ziegler shaft, near Nürschau. This shaft struck coal at a depth of 436 feet. It was found to have struck the coal not far from the northern limits of the seam. The shaft was then sunk a farther depth of 197 feet, and then

* *Zeitschrift des Vereines deutscher Ingenieure*, vol. xlii. pp. 1429-1436.

† *Annales des Mines*, vol. xv. pp. 101-114.

‡ *Glückauf*, vol. xxxiv. pp. 953-967.

§ *Zeitschrift des Vereines deutscher Ingenieure*, vol. xlii. pp. 1341-1348, with twenty-two illustrations in the text and one plate.

|| *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlvi. pp. 495-499, 509-513, and 529-533, with five plates.

a cross cut was put out which struck the seam at a distance of 3444 feet, and this now forms the main gallery and drainage level of the mine. Further coal deposits have since been discovered at a distance of 6560 feet from the shaft. Various difficulties in working were experienced, partly owing to the awkward position of the shaft, and partly owing to the seams worked being but thin, while the quantity of water met with was considerable. Electric transmission of power was scarcely met with in mining practice at the earlier period of these colliery workings, but a plant for this purpose has now been laid down, and has given much satisfaction. It is utilised for a variety of purposes, full details as to which are given.

Mine Timber.—H. Louis* gives some further † notes on pit-props, and shows from the results of tests that oak props are weaker than white wood. Probably this is due to the nature of the prop as such which gives way at points of local weakness, as in small samples oak withstands greater crushing loads. The author also gives a resumé of Dütting's experiments, and quotes his results as follows:—

| | Props Tested Immediately after Felling. | Props Tested after Five Months. | Props Tested after being Dried. |
|-----------|---|---------------------------------------|---------------------------------------|
| | Ton per Square Inch. | Ton per Square Inch. | Ton per Square Inch. |
| . . . | 1.45 | 1.59 | 1.62 |
| . . . | 1.25 | 1.36 | 1.51 |
| . . . | 1.17 | 1.21 | 1.32 |
| Oak . . . | 1.10 | 0.95 | 1.32 |

G. L. Kerr ‡ deals generally with timbering and supporting underground workings. After giving statistics of accidents due to falls of roof and sides, the various forms of timbering and their costs are described, and its strength and preservation are also dealt with. Brick walls and girders are also referred to.

J. Birkinbine§ gives a general account of mine timbering in the United States, and illustrates some of the heavy work that has to be maintained.

* *Transactions of the Institution of Mining Engineers*, vol. xvii. pp. 14-18.

† *Journal of the Iron and Steel Institute*, 1898, No. II. p. 434.

‡ *Transactions of the Institution of Mining Engineers*, vol. xvi. pp. 230-248, with two plates.

§ *Cassier's Magazine*, vol. xv. pp. 20-31.

Driving Levels.—Domage * has published some remarkable results obtained in driving the submarine heading at the Bouches du Rhône Colliery during the month of June last. Work was carried on in three shifts of eight hours, there being seventy-eight shifts during the month. The rock traversed is a limestone sufficiently homogeneous to permit of the employment of a rotary drill, and sufficiently hard and compact as to render timbering unnecessary. The Bornet electric drill was used. The dynamo was driven by a turbine worked by water from a vein encountered in driving. It supplies electricity for a Mortier fan and for a series of lamps, as well as for the drill. The face in June last was about $3\frac{1}{2}$ miles from the entrance to the heading. The excavated material was removed by the aid of an endless rope. The average advance per twenty-four hours was 5·676 metres, or 1·892 metres per shift. The maximum advance was 6·700 metres. The mean advance for each setting of the drill was 0·964 metre. The 153 settings of the drill in June last necessitated the boring of 1791 holes, with an aggregate length of 1828·7 metres. The average depth of the bore-holes was 1·021 metre. Each shift worked independently, and premiums were given daily to the workmen of the shift that effected the greatest advance.

Coal-Drills.—Illustrations are given † of a German drill used in collieries. It has a wooden standard, and weighs 60 lbs.

A. Czermak ‡ describes and illustrates the Jones percussion hand-drill, observing that it is probably but little known in Austro-Hungarian mines.

Illustrations have appeared § of the Meissner electric rock-drill. It is of the percussive type, driven from a fly-wheel shaft by a crank. Motion is communicated to this shaft through a flexible shaft from the detached motor.

Coal-Cutting Machinery.—G. C. Allsebrook || deals with the various points favouring the introduction of coal-cutting machinery, its effect on the labour question, the means used for driving, and the

* *Comptes Rendus Mensuels de la Société de l'Industrie Minière*, 1898, pp. 179-180.

† *Zeitschrift für Berg-, Hütten-, und Salinenwesen im preussischen Staate*, vol. xlvi. p. 103.

‡ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlvi. pp. 687-689; fourteen illustrations.

§ *Engineering and Mining Journal*, vol. lxi. p. 759.

|| *Transactions of the Institution of Mining Engineers*, vol. xvi. pp. 67-82.

methods of setting out the work. The various types of machines are considered under five heads—core-cutting heading-machines, percussion machines, chain machines, rotary-bar machines, and rotary-wheel machines. Various forms of each type are briefly described.

T. H. Barr* describes the Hurd and the Clarke coal-cutting machines, both of which are driven by electro-motors. The Hurd machine is of the bar-cutter type, with arrangements for changing the cutter from one side to the other, and is in use in Staffordshire. The Clarke machine is of the wheel-cutter type, and is in use in Scotland. Particulars of their work are given.

A list has been compiled† to show the makers of coal-cutting machinery in England, and the kind of machinery made. These include eight makers of compressed air-driven machines, and ten of electrically-driven machines.

Some illustrations of the Jeffrey long-wall coal-cutting machine at work underground have appeared.‡ The machine is compact, being only 8 feet 2 inches long, 3 feet 8½ inches wide, and 19 inches high; it cuts from 3 to 6 feet under, making a kerf of 6 inches. The motor, of 25-horse-power, is claimed to be free from sparking; the starting switch is completely enclosed, and the connections from the trailing cable to the machine enclosed within a metal cover.

E. W. Parker§ states that in 1891 541 coal-cutting machines were at work in the United States, while in 1897 there were 1198 machines, and the output had increased to 22,649,000 tons. Pennsylvania, though having fewer machines at work in 1897 than Illinois, had adopted them more rapidly in the last few years. Machines driven by electricity were made in 1879. Cutter-bar machines have generally been discarded, as they are much less economical than those of the types in most frequent use, the pick and the chain-breast. This last was brought out simultaneously by three companies in 1894. Some long-wall machines are manufactured, but chiefly for export, as the long-wall system of mining is comparatively little used in America. Regarding the effectiveness of machines, the author thought there were few bituminous mines with level seams, or seams having low dips, where machines could not be used to advantage. A dip of over 12 degrees makes machine-mining hard, but some machines with self-

* *Transactions of the Institution of Mining Engineers*, vol. xvi. pp. 447-452.

† *Iron and Coal Trades Review*, vol. lvii. p. 777.

‡ *Colliery Guardian*, vol. lxxvi. pp. 604, 649.

§ *Transactions of the American Institute of Mining Engineers*, New York Meeting, 1899.

hauling trucks can work in seams with dips as high as 14 degrees. The best saving is made not by giving the machines to experienced hand-miners, but by instructing new men in their use.

V. Waltl * further deals with the use of machine-getters in collieries. He specially refers to and describes the Hardy hand-drill as modified by Leyendecker, and comparative results obtained in practice are shown in tabular form.

L. D. Howard † deals with the necessity for greater care in the use of coal-cutting machinery.

An illustration has appeared ‡ of the Sullivan shearing machine. A reciprocating cutter is carried by a radial arm movable in a vertical plane by a rack and pinion. The machine is mounted on a truck.

Explosives and Blasting.—W. Blakemore § discusses recent experiments in blasting with compressed cartridges. He shows that the effect on the coal is the same as that of loose black powder. The cost is 25 per cent. greater, but the quantity required is 30 per cent. less. Moreover, compressed cartridges are safer and easier to handle.

According to Victor Watteyne and Lucien Dencël,|| the consumption of explosives in Belgian collieries per 1000 tons of coal mined averaged in 1897 :—

| | Lbs |
|--|------|
| Blasting powder | 57.0 |
| Dynamite and other high explosives | 23.4 |
| Safety explosives | 13.2 |
| Total | 93.6 |

The use of black powder decreases every year.

J. Muck ¶ gives the results of some tests of safety explosives, including Wetterdynamite, Progressite, Dahmenite, and (new) Westfalite, and some new compounds of ammonium nitrate and nitro-cellulose.

O. Guttmann ** deals with the present state of knowledge, and some suggestions for the future with regard to explosives that have been put on the market for the purpose of blasting in coal-mines, where the presence of inflammable gas and coal dust constitutes a danger under

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlv. pp. 706-707. See also *Journal of the Iron and Steel Institute*, 1898, No. II. p. 436.

† Paper read before the Ohio Institute of Mining Engineers, January 1899.

‡ *Mines and Minerals*, vol. xix. p. 169.

§ *Journal of the Canadian Mining Institute*, vol. i. pp. 3-9.

|| *Annales des Mines de Belgique*, vol. iv. No. 1.

¶ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlvii. pp. 103-107.

** *Journal of the Society of Chemical Industry*, vol. xviii. pp. 6-15.

ordinary circumstances. The opinions expressed in various foreign reports are discussed, and also the temperature of ignition and the methods of using explosives.

The report by Major A. Cooper Key* for 1898, to which is appended that for 1897, on the work of the Home Office testing station has recently appeared. The conditions of test have not changed. Various new explosives have been added to the permitted list, and amongst these is gunpowder to which certain cooling additions are made. Tests made on the inflammability of anthracite dust show that it cannot be considered as free from danger. Other tests have been made to determine the distance at which detonators are fired by the explosion of an adjacent detonator.

Fillunger† describes an explosion in Moravian Ostrau of fulminating caps for the Tyrmann blasting process. These are packed in two boxes, "wood wool" being placed between them. It is thought that the explosion took place during the opening of the inner box, which is closed by four screws. One of these screws having probably projected inside the box and been brought into contact with the explosive contents of one of the fulminators when an attempt was made to draw the screw. Further investigation has since shown that these screws are often put in in a most dangerous way. Five thousand caps ignited in the magazine and two lives were lost.

W. Maurice,‡ in the fourth part of his comprehensive paper on electric blasting, describes in detail representative patterns of each class of electric exploders, including dynamo exploders, magnetic exploders, and batteries, both primary and secondary. The method of firing with current from electric mains is also dealt with. Conductors and methods of testing the fuzes, circuits, and machines are then described. Blasting in shaft-sinking and in coal is considered, together with the treatment of missed shots, and the dangers of electric blasting with high explosives is referred to. A series of twenty-five rules as to shot-firing and explosives is appended, and in two plates illustrations of the various exploders are given.

Krepler§ in discussing the use of explosives in fiery mines, observes that this is the greatest source of danger in connection with fire-damp explosions. There has, therefore, been a constant endeavour to minimise the danger due to this cause as far as could possibly be

* *Home Office Report*, 1899.

† *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlvii. pp. 16-17.

‡ *Transactions of the Institution of Mining Engineers*, vol. xvi. pp. 128-182.

§ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlv. pp. 720-721.

effected. In dangerous places the use of dynamite is now being abandoned in favour of explosives containing no nitro-glycerine, while the use of high explosive detonators is being replaced by other methods of firing the charge. These latter the author specially refers to. The question of shot-firing is generally considered, and the precautions necessary to be taken briefly mentioned. Given a perfectly satisfactory detonating method, and a satisfactory explosive free from nitro-glycerine, all danger of gas explosions due to shot-firing would be abrogated.

Working Coal. — J. T. Beard* discusses the conditions that determine the system by which a given coalfield should be worked. He gives detailed descriptions of the pillar-and-stall and long-wall methods, with special reference to their adaptation to certain conditions.

W. G. Mitchell† describes the long-wall method employed at Jellieston Colliery, Ayrshire, for working three seams of coal lying close together. A section shows top coal 6 feet, sandstone fakes $4\frac{1}{2}$, mid coal 5, dark fakes $3\frac{1}{2}$, bottom coal $4\frac{1}{2}$, and sandstone $4\frac{3}{4}$ feet. The inclination is one in six, and the coal is worked to the rise. The bottom seam is worked first, then the mid coal, and lastly the top coal.

A system of working adopted in the Tesla coal-mines, which have recently been opened up in California, has been described by Mr. F. L. Horsewill‡ as the Angle Work System. The seam is 7 feet in thickness, without partings, and has a roof of shelly slate and a hard sandstone floor. The coal is divided up into panels, which are split up into pillars placed at an angle with the main roads, and the coal obtained by working the pillars is sent down shoots.

In a paper read before the Ohio Institute of Mining Engineers, Edward Jones urged the advantages of long-wall working. Compared with pillar-and-stall working, the long-wall method presents the advantages that the life of the mine is prolonged, that a larger proportion of lump coal is obtained, that the cost of mining is less, that haulage is more economical, that ventilation is facilitated, and that less timbering is required.

A long series of articles on board-and-pillar systems of working coal

* *Mines and Minerals*, vol. xix. pp. 245 247, 292 293.

† *Journal of the British Society of Mining Students*, vol. xxi. pp. 80 83.

‡ *Mines and Minerals*, vol. xix. pp. 145 147.

has appeared.* The subject is treated partly from a mathematical aspect.

J. A. Ede † discusses the progress and improvement in coal-mining, and contrasts the methods of ten years ago with the elaborate labour-saving machinery now in use.

O. E. S. Whiteside ‡ compares the getting of coal from places driven across the pitch nearly in the direction of the strike and parallel with the main roads, with the same operation in places at right angles to the strike, in the conditions that obtain in pitching seams.

For some time past a new type of wedge has been in use in several collieries in Westphalia and Saarbrücken for breaking down coal. Boreholes are drilled and the wedge inserted. The coal is loosened, and is easily broken down by the pick. The wedge, which is the invention of Heise,§ is a combination of the screw and the wedge.

Coal-Mining in Belgium.—J. Smeysters|| considers in detail the progress that has been made in recent years in the Charleroi Basin, Belgium. The collieries, he points out, have greatly increased in depth in recent years, the Marchienne Colliery, for instance, as well as that of Marcinelle-Nord, having each attained a depth of more than a kilometre (0·63 of a mile). The depth of about a thousand yards is attained at several collieries, and these are soon to be sunk to a still greater depth. Quite a number of pits are more than 700 yards in depth. With the attainment of depth, mining difficulties have had to be overcome, and in connection with these the author draws attention to the increased use of iron and steel in place of wood as supports, the continually increasing use of ventilation shafts for winding purposes, and the use of stronger and simpler machinery and larger ventilating plants as well as pumping appliances. Mechanical haulage underground has also shown signs of progress, and is likely to be extensively employed before long. Electricity as a source of power is employed at many of the collieries in the Charleroi district for winding, pumping, and other purposes. Considerable progress, too, has

* *Colliery Guardian*, vol. lxxvi. pp. 197, 241, 288, 336, 395, 438, 605, 645, 740, 786, 845, 876, 924, 967, 1016, 1109, 1156, 1197.

† Paper read before the Ohio Institute of Mining Engineers, January 1899.

‡ *Canadian Mining Review*, vol. xviii. pp. 37-38.

§ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlvii. pp. 661-662; two

|| *Annuaire de l'Association des Ingénieurs Sortis de l'Ecole de Liège*, vol. xii. pp. 1-10, with map.

been made in the utilisation of safety methods for the prevention of explosions.

M. Ghysen * deals in detail with the Marchienne Colliery. The present Marchienne company was started in 1885. The upper beds of coal are faulted by the Tombe fault, and many of the older shafts had not been sunk to an adequate depth. The present company sank one of the shafts to a much greater depth, cutting successively the Broze seam at a depth of 802 metres, the Cense seam at 866 metres, the Maton seam at 894 metres, and the Caillette seam at 1006 metres. These are the seams at present worked, but the Dix Paumes and Grande Veinette seams are also met with at a depth of 1200 metres. In neighbouring collieries to the north, these seams are exploited on a large scale. In addition to the Tombe fault, which has caused a large throw in the upper workings, two other faults—those of Liège and Carabinier—also traverse the workings. The first ought to have been found when sinking the shaft, but was not noticed. It was subsequently observed elsewhere, however. The winding shafts, the winding plants, and the methods of mining generally are considered.

At the Aiseau-Presses Collieries, according to J. Collin,† three kinds of coal are raised, varying from a coal yielding 14 to 15 per cent. of volatile matter, to an anthracitic coal. The seams dip to the south at an angle of from 25 to 52 degrees from the horizontal. The semi-bituminous coal mined at the Roselies portion of these collieries contains about 14 to 15 per cent. of volatile products, and is of remarkable purity, containing only 4 to 5 per cent. of ash when hand-picked. The plant and the methods of working are fully described.

Mine Pumps.—An illustration of the hydraulic power pump at the Haughhead Colliery, Uddingston, near Glasgow, has recently appeared.‡ It is intended to raise 500 gallons per minute to a height of 840 feet. The plant consists of a Lancashire boiler, 24 by 7 feet, working at 160 lbs. pressure, an economiser, and a set of triple-expansion, jet-condensing pumping engines capable of indicating 200 horse-power at fifty revolutions. The cylinders are 14, 23, and 38 inches in diameter with a 2-foot stroke, and with three ram pumps 6 inches in diameter and 2-foot stroke working direct from the piston rods. The engines

* *Annuaire de l'Association des Ingénieurs Sortis de l'Ecole de Liège*, vol. xii. pp. 10-20.

† *Ibid.*, pp. 20-32.

‡ *Engineer*, vol. lxxxvii. pp. 339-340.

deliver water at a pressure of 700 lbs. at the surface, and this is conveyed by 6-inch pipes to and from a three-throw hydraulic-power pump in the mine.

A fully-illustrated description of new electric pumping-plant recently installed at Arniston Colliery, Gorebridge, has recently appeared,* giving details of the motors, switches, and pumps. A section of the workings is also appended.

A. W. K. Pierce † discusses the following questions:—What type of pump is to be used? What system of electrical transmission? What type of electrical apparatus? What head shall the pumps be operated against? What size of pump, and what capacity shall be used? Three-throw pumps driven by three-phase motors supplied with currents at 250 volts are advocated. Illustrations of various pumps and motors are given.

S. H. Bunnell ‡ describes the application of electric power to pumping machinery, and gives illustrations of electrically-driven sinking, mining, and other pumps.

In some notes on suction pipes, D. W. Mead § discusses the factors influencing the suction-lift—atmospheric pressure, quantity of water to be raised, and character of pipe used; proportion and arrangement of suction-valves and water-passages of the pump; temperature of water; and amount of dissolved gases in water.

O. H. Mueller || discusses the forms and details of modern pumping machinery for use in mines, and the methods of transmitting power to underground pumps.

A paper on underground pumping-engines has been published by Paul Habets.¶ Underground pumping-engines, whether worked by steam, hydraulic-power, or electricity, are nearly equivalent as regards the consumption of steam. In this connection methods with gearing are, however, more economical whenever a pumping-engine is laid down of greater power than that actually required under ordinary circumstances, in order to provide for an increase in the quantity of water, in which case the pump does not work continuously, and if it be driven directly by a steam-engine, its rate of consumption will

* *Iron and Coal Trades Review*, vol. lvii. pp. 778-779.

† *Ibid.*, vol. lviii. pp. 283-285.

‡ *Engineering Magazine*, vol. xvi. pp. 429-440.

§ Paper read before the Western Society of Engineers, through the *Iron and Coal Trades Review*, vol. lviii. p. 631.

|| *Cassier's Magazine*, vol. xv. pp. 487-498.

¶ *Revue Universelle des Mines*, vol. xlv. pp. 281-294.

increase in inverse proportion to the actual time it is at work. The advantage of reduced consumption, with suppression of the disadvantages caused by underground steam-pipes, often compensates for the higher first cost of geared pumping-engines. Hydraulic transmission has the advantage of great simplicity in the plant and its maintenance. The steam consumption of slow-running compression engines, which may be fitted with very perfect valve-gear, may be reduced below $16\frac{1}{2}$ lbs. per horse-power per hour; and with compression-engines not consuming more than $14\frac{1}{4}$ lbs. per indicated horse-power the consumption by the hydraulic pumping-engines will be less than 22 lbs. per horse-power in water raised. Electricity is better suited for long distances, while more readily lending itself to working appliances of all kinds; but the special conditions of each case will decide which means of transmitting power should be adopted.

Owing to the fact that the lifts of coal standing above each of the deep levels at the Anzin Collieries are only sufficient for seven years' working, an underground pumping-engine driven by electricity has been erected, in order to avoid the expense of the large walled chambers required for steam pumping-engines, an expense which, in some instances, has amounted to £1200. According to S. Barry and P. Baudot,* the installation comprises a 100-horse-power Corliss engine at the surface, with a 4-pole Gramme dynamo, giving a continuous current of 125 amperes at 500 volts, and an underground motor similar to the surface dynamo, except that it is shunt instead of compound-wound. The pumps, three in number, are single-acting plungers of $3\frac{1}{2}$ feet diameter and 8 feet stroke. The cost of the installation was £2916, of which £160 is chargeable to the engine-room underground. When the present level is worked out, the plant can easily be adapted for working at lower levels.

An illustrated description has been published † of the electric underground pumping-plant at Zollverein Colliery, at Caternberg. It has been in successful operation for a year, having proved itself to be more economical than if hydraulic-power, pump-rods, or underground steam-engines were employed.

An elaborate memoir on recent underground pumping-engines is published by B. Gerdau.‡

* *Bulletin de la Société de l'Industrie Minérale*, vol. xi. pp. 599-619.

† *Der Gnom*, vol. i. No. 18.

‡ *Zeitschrift des Vereines Deutscher Ingenieure*, vol. xliii. pp. 57-65.

He finds that the steam consumption is as follows :—

| | Per H.-P. Hour. Kilos. |
|--|------------------------|
| Pumping-engines above ground with rods | 11 to 12 |
| Underground steam pumping-engines | 10·5 |
| Underground hydraulic pumps | 10·0 |
| Underground electric pumps | 10·6 |

Illustrations are given * of the new pit-head gear and of the four Davey compound differential pumping engines for the Miike Collieries, Japan. These have cylinders 45 inches and 90 inches diameter by 12 feet stroke. Each engine actuates two sets of 22-inch pumps, and at six strokes per minute will deliver 2300 gallons per minute from the bottom of the shaft, a depth of 900 feet. The sinking lifts are being suspended by rods and screws, and lowered as the sinking proceeds. The pit-head frame is of steel and is provided with capstan pulleys and two 30-ton capstans for lowering the pump work.

F. W. Klönne † observes that in 1879 there was a sudden inburst of water at the Dux-Ossegg mines, by which five large mines were flooded, and twenty-one men lost their lives. In the subsequent endeavours to reclaim the drowned-out pits the author made a lengthened series of very careful observations of the height of water in the shafts. He found that there was a distinct daily movement similar to ebb and flow. He does not consider it at all possible for this to be an ebb and flow in the ordinary sense of the word, but he considers it to be due to earth movements. He observes that the Teplitz springs, at no great distance away, stopped for a time when the great Lisbon earthquake took place, and adds that it may be assumed with almost absolute certainty, that this pulsating movement of the water has its origin in the earth interior, and he considers that in connection with the escape of fire-damp not only has the height of the barometer to be considered, but also the position of the sun and moon, as these water movements show that he has examined into and now describes. The author refers to another instance in which such water movements appear influenced in this way by the position of the sun and of the moon. Considering the volume of the collieries filled by water in the first twenty-four hours after the irruption of water into them in the case the author describes, the author calculates that the quantity of water so entering was as much at first as 28,253 cubic feet per minute.

* *Iron and Coal Trades Review*, vol. lviii. pp. 508-510.

† *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlv. pp. 623-626, with a sheet of illustrations.

The Ventilation of Collieries.—The best relative positions of up-cast and downcast ventilating shafts are discussed by Von Braunmuhl.*

Air crossings made of timber and in the rock are compared, and a pronouncement is made in favour of the former.†

Steinhoff ‡ describes the underground fans used for compression ventilation at the Schlesien and Deutschland pits in Upper Silesia. Several Mortier fans are at work in these collieries. A comparison is made between exhaust and compression ventilation.

A. Godeaux § deals with the compensation of fans driven by direct acting engines.

R. C. Carpenter || describes his investigation of a centrifugal fan which was made adjustable in many respects as regards size and form of blades, and of the outlet and inlet.

A fan which has recently been installed at the Bliss and Auchincloss shafts at Wilkes-Barre is a combination of the Guibal and the Rammell.¶ It takes air from both sides and has tapering vanes between a plate casing. The fan is 35 feet in diameter with sixteen vanes having a radial length of 9 feet and a width at the base of 9 feet tapering to 6 feet at the periphery. The vanes are so shaped as to make what may be called a forward curve, which at the periphery is perpendicular to the circumference of the fan. The engine is a 26 by 48 inch Corliss, using steam at about 90 lbs. pressure. The airway to the fan on the side next the engine is enclosed by steel plates to bring the engine as near the fan as possible, shortening the shaft and reducing the strains on it. The two airways to the fan are 9 feet square. The passage under the fan at its lowest point is 6 feet high. The top of the *erasée* chimney is 32 feet from the ground and 20 feet square inside. There is a sliding shutter with counterpoise in the chimney.

E. Brackett ** describes a fan recently built at the Patton Colliery, near Lonaconing, Maryland, for compression ventilation. The fan is a modified Guibal, with tapering blades and casing, and a V shutter. Some tests are given.

* *Zeitschrift für das Berg-, Hütten- und Salinenwesen im preussischen Staate*, vol. xlvii. pp. 89-127.

† *Mines and Minerals*, vol. xix. p. 366.

‡ *Zeitschrift für das Berg-, Hütten- und Salinenwesen im preussischen Staate*, vol. xlvi. pp. 280-294.

§ *Revue Technique*, through the *Colliery Guardian*, vol. lxxvii. p. 248.

|| Paper read before the American Society of Heating and Ventilating Engineers, through the *Engineering News*, vol. xli. pp. 79-80.

¶ *Engineering and Mining Journal*, vol. lxvii. pp. 114-115.

** *Mines and Minerals*, vol. xix. pp. 370-372.

Some experiments with hydrometers and anemometers are described by Rateau.* When testing currents of air with the drum anemometer the results obtained were found to be too high. This is attributed to the inertia of the drum. In twelve experiments the greatest excess was 33·5 per cent., and the least 1 per cent. Correct results are obtained if the current is homogeneous and regular. In order to obtain the best results the wings must be inclined at an angle of 45 degrees, and the moving wheel made as light as possible.

Safety Lamps.—Illustrations are given † of the Wolf safety lamp, and of the apparatus used for filling and testing it.

Illustrations have appeared ‡ of the "H" safety lamp devised by S. Humble. All removable parts are connected by bayonet joints, and are self-locking. Other joints are made with rivets. Each part locks the part previously put together, and the final lock is magnetic.

A. Abrassart§ describes an improved form of the Sussman electric lamps, and means for charging them, as used in some Belgian collieries.

The Wüste and Rupprecht incandescent lamp gives a light of a little more than one candle power, and after the accumulators have been charged freshly it will last for twelve hours, the accumulators giving the full light for a relatively very long time. The total weight is about six lbs.||

Fire-Damp Detection.—The Lyncker and Schropp gas indicator ¶ is one of the diffusion type, with a porous cell into which the gas diffuses, and raises a flexible diaphragm to complete an electric alarm circuit.

Paul Fuchs ** describes a continuously acting apparatus for determining the proportions of fire-damp in the air of mines.

Spontaneous Combustion in Collieries.—J. S. Haldane and F. G. Meachem †† discuss the relation of underground temperature and

* *Annales des Mines*, vol. xiii. pp. 331-385.

† *American Manufacturer*, vol. lxiv. pp. 27-28.

‡ *Iron and Coal Trades Review*, vol. lvii. p. 780.

§ *Société des Ingénieurs Sortis de l'Ecole des Mines du Hainaut*.

|| *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlvii. pp. 750-752.

¶ *Ibid.*, vol. xlvii. p. 77.

** *Zeitschrift für das Berg-, Hütten und Salinenwesen im preussischen Staate*, vol. xlvii. pp. 73-77.

†† *Transactions of the Institution of Mining Engineers*, vol. xvi. pp. 457-492.

spontaneous fires in coals to oxidation and to the causes which favour it. In previous papers it has been shown that the natural temperature in the thick coal at Hamstead Colliery is considerably below that of the working places and return air roads, and that black damp is the residual gas after oxidation of some substance in the coal or strata. Experiments have shown that the loss of oxygen is proportionately greater than the gain of carbonic anhydride in the air, not only in collieries, but also in metalliferous mines. Coal when exposed to air absorbs oxygen, but does not liberate much carbonic acid, so the presence of that gas is ascribed to the action of sulphuric acid, produced by the oxidation of pyrites, on carbonates. Though admitting that the oxidation of carbonaceous material is a source of heat, yet the authors ascribe the larger proportion of the heat generated to the oxidation of the pyrites. On this point, however, much objection to the authors' views has been expressed in subsequent discussion. At any rate, the heat generated is much greater than the amount escaping in the return air, and accounts for the increase of temperature in the mine. The authors then deal with the various forms of fires that occur underground, and with the precautions that should be taken to guard against them and to overcome them.

J. Ashworth* discusses the questions of water, coal-dust, spontaneous combustion, and gob fire. He thinks that it is not wise to water a mine which is subject to spontaneous combustion, and that a very dry and cool ventilation air-current is the best safeguard against spontaneous combustion and explosion from coal-dust, and that until some better means of rendering a mine safe against an explosion of coal-dust is discovered, a wet length of road or zone is the best protection, and will add the minimum of risk to a mine subject to spontaneous combustion.

The precautionary measures to adopt with a view to minimise the dangers of shaft fires are dealt with by J. Mayer.†

In an official report Dröge‡ describes the means used in the Saar district for laying dust. Reference is made to the Camphausen, Krentzgraben, Maybach, and König collieries. Water taken from the rising mains or a higher level in the mines is passed through strainers or settling tanks and is distributed by main and branch pipes of which the dimensions and other particulars are given. Meters are used for

* *Colliery Guardian*, vol. lxxvii. pp. 253-254.

† *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlv. pp. 525-529, 539-544, and 557-559.

‡ *Colliery Guardian*, vol. lxxvi. pp. 1057-1059.

measuring the water. The Meissner method of soaking the coal *in situ*, continuous and intermittent sprinkling with hose, and wet zones, are all employed. The advantages and disadvantages of damping are discussed, and some particulars are given of the cost and maintenance.

Coal Consumption at Collieries.—An elaborate paper by R. Van A. Norris* gives an account of an investigation made to determine the causes of a large discrepancy between the coal used for firing at the Lykens Valley Coal Company and the Summit Branch Coal Company in Dauphin county, Pennsylvania. The former used 4381 tons for boilers of 3323 horse-power, and the latter 7306 tons for boilers of 5313 horse-power in twenty-six working days. The results of the investigation are set forth in tabular form and are discussed in detail, the loss being ascribed to leakage, oversized engines, and other defects. Amongst other points, the advantages of winding water as compared with pumping are advocated.

A. D. Smith† gives some particulars of the consumption of coal for raising steam at various anthracite mines in Pennsylvania, and summarises them as follows:—

| | Shipments and Local Sales. | Coal Used for Steam. | |
|------------------------------|-------------------------------|-------------------------|-----------|
| | Tons. | Tons. | Per Cent. |
| Northern Field | 23,360,774 | 1,645,239 | 7.0 |
| Eastern Middle Field | 4,912,366 | 776,687 | 15.8 |
| Western Middle Field | 8,347,669 | 1,091,324 | 13.1 |
| Southern Field | 4,924,113 | 683,754 | 13.9 |
| Totals | 41,544,922 | 4,197,004 | 10.1 |

J. A. Longden‡ discusses the amount of coal consumed for raising steam at collieries. At eight collieries the consumption was 5.2 per cent. of the output, but it ranged from 3 to 10 per cent. It may be assumed for a nine-hours' day of winding coal where there is no water pumping or dirt winding, that the consumption should be one per cent. for each 300 feet of depth at a colliery which has been in operation twenty years. With modern appliances and high-pressure steam this may be reduced.

Gradual changes during the last ten years have been taking place

* Paper read before the American Society of Mechanical Engineers, through *Engineering*, vol. lxvii. p. 41.

† *Engineering and Mining Journal*, vol. lxxvii. pp. 81-82.

‡ *Transactions of the Institution of Mining Engineers*, vol. xvi. pp. 366-376.

in the character of the boiler plants in the anthracite district of Eastern Pennsylvania. The old cylindrical type has gradually been superseded by improved tubular forms, and now some of the most economical and thoroughly equipped plants in the country are to be found at the anthracite collieries. One of the most recent mine boiler plants is that of the Lehigh Valley Coal Company at its Hazleton Shaft Colliery, Hazleton. The battery of boilers consists of eight nests of two boilers each, each boiler being 72 inches in diameter, 18 feet long, and containing seventy-six 4-inch tubes. Each boiler has a commercially rated capacity of 150 horse-power, thus giving the entire plant 2400 horse-power. Both induced and forced draught can be used, fans being employed for this purpose, and the products of combustion are drawn through tubular economisers. Illustrations are given.*

Hugh Bramwell † describes the condensing arrangements at collieries, referring to various forms of evaporative and other condensers and to appliances for cooling condensing water.

Sanitation in Collieries.—C. Tinus ‡ refers to further cases in which, in Austria, the ill-health and even death of miners has been found attributable to the parasite *Ankylostoma duodenale*. § The author considers that it is of much more frequent occurrence than has hitherto been considered to be the case.

J. Barrowman || discusses the health conditions of coal-mining, and thinks that with one or perhaps two exceptions there are no diseases peculiar to the miner's calling. These exceptions are an affection of the eyes termed "nystagmus," and, in a lesser degree, that disease of the respiratory organs which usually goes by the name of "miners' asthma." A short description of these diseases is given.

H. Rössner ¶ describes the precautionary measures prescribed by the Austrian Government in connection with the working of the collieries in the Ostrau-Karwin district. The exact duty of every employé in case of accident is formulated in detail.

Subsidence Caused by Mining.—S. R. Kay ** deals with the effect of subsidence due to coal workings on bridges and other structures.

* *Mines and Minerals*, vol. xix. pp. 106-108.

† *Proceedings of the South Wales Institute of Engineers*, vol. xxi. pp. 151-167.

‡ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlvi. pp. 626-629.

§ *Journal of the Iron and Steel Institute*, 1898, No. II. p. 449.

|| *Cassier's Magazine*, vol. xv. pp. 270-281.

¶ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlvi. pp. 640-642.

** *Minutes of Proceedings of the Institution of Civil Engineers*, vol. cxxv. pp. 114-173.

This subject has frequent application in the busy industrial districts of the coalfields, where buildings, bridges, and tunnels are often found in the immediate neighbourhood of colliery operations. It is necessary, therefore, in designing works in such districts, to know, first, the principles of subsidence following the working of coal, to determine the position and character of the works; secondly, an approximation to the area necessary to be left unworked for the protection of the same; and, thirdly, how the design may be suited to the supposition that the coal may afterwards be worked without any solid pillar being left for support.

Subsidence always follows coal working where no pillars are left, and is generally proportionate to the thickness of material excavated. The depth regulates roughly the duration of the movement. Subsidence might be modified by tight packing of the goaf, where no coal was left for support, under the area to be protected.

Faults are always to be avoided in the erection of permanent works. Fractures are rare at the surface if the depth exceeds one hundred yards, unless the thickness of the seam or some intervening rock strata is great. Subsidence is slower in deep than in shallow mines. The effect is felt in the case of buildings more in the nature of a "pull over" than of an actual break. The strain moves with the working face, and is not brought into play unless the working ceases for a sufficient time to cause it to become operative. Spirit levelling over fairly level workings 120 yards and 330 yards deep proved in the former case that subsidence closely followed the extraction of the coal, and continued for three and a half years, amounting to 70 per cent. of the thickness excavated; in the latter case it followed somewhat later, continued for four years, and amounted to 64 per cent. of the thickness excavated. The movement was uniform, without breaking the surface. Subsidence around pillars is most irregular in its action, and no theoretical formulas could be enunciated to apply to all cases, giving the size and position of the support necessary. All rules for that object were empirical, and subject to modification by local considerations. If absolute immunity was to be secured, an ample pillar should be left.

If the site of the works be over a fairly large area of goaf, even settlement might be expected, and when complete the surface will simply be lowered. Works should be built away from the edges, and not until two or three years had elapsed. Arches should be avoided in favour of steel superstructure. Canal banks must be raised two-

thirds the thickness of the excavations, and locks must be protected by pillars. Under normal conditions the author gives a formula, which shows that the radius of the pillar should be $1\frac{1}{4}$ times the square root of the depth multiplied by the cube root of the thickness in feet. In inclined seams, the pillar should be displaced towards the rise side by an amount equal to $d \tan \frac{1}{2} \theta \cos \theta$, where d is the depth and θ the angle of the dip. Pillars of large size at depths of over 300 yards may be ribbed, leaving openings 20 yards wide. This is quite safe, and gives much economy.

The rights of the owner of the surface, and of the minerals in relation to the effects of surface water, were dealt with a short time ago by L. Michel, and a short account of his researches, chiefly from the legal point of view in France, has recently appeared * as a translation.

History of Coal-Mining.—R. L. Galloway † has published a work of over 500 pages containing a history of coal-mining from the earliest times. The first use of mineral coal seems to have been somewhere about the time of Alexander the Great, but there does not appear to be any foundation for its supposed use either by the Early English or Anglo-Saxons, although it was employed, but only to a small extent, by the Romans during their occupation of Britain. There are no direct records relating to the employment of the mineral, but it is possible that a commencement may have been made to utilise it, to a small extent, in the Norman period. The right to dig for coal is mentioned in records of the earlier part of the thirteenth century, but of mines we have no mention until its close. In the fifteenth century the extended use of coal in domestic purposes may be noted. The failure of the wood supply caused coal to come into general use for domestic purposes during the sixteenth century, and the first foreign exports also took place. Numerous collieries were at work in all the present mining districts, and attention was directed to the presence of noxious gases, about which more enlightened notions began to prevail. With the close of the reign of Queen Elizabeth, the first great period in the history alike of the coal trade and of coal-mining may be said to have come to an end, as the coal was almost all obtained from shallow collieries above the level of free drainage.

The first recorded accident from fire-damp seems to be the one entered on the register of St. Mary's Church, Gateshead, under date

* *Colliery Guardian*, vol. lxxvii. pp. 112-113.

† "Annals of Coal-Mining and of the Coal Trade." London: *Colliery Guardian* Company.

October 14, 1621, on the interment of "Richard Backas, burned in a pit." Railways began to be used about the middle of the seventeenth century, the first distinct allusion to them being made in a document dated 1660. It was water, however, that presented the greatest obstacle to mining operations, alike both in sinking and working the pits, and although Savery's patent is dated 1698, it was not until Newcomen in 1712 erected the pumping-engine between Walsall and Wolverhampton that the problem came near to solution. The subsequent improvements of Watt, and the more liberal employment of iron, led to the extended use of the steam-engine, and laid the foundation for that development of the mining industry which has continued from the end of the eighteenth century to the present time. Other notable improvements introduced during the eighteenth century were the adoption of gunpowder for rock-blasting, the artificial ventilation of the workings by fire, and the proper direction or coursing of the air current. Horses were also employed for underground haulage and railways, and four-wheeled vehicles substituted to some extent in place of sledges, previously employed.

The beginning of the nineteenth century was marked by the greatly increased use of coal, the invention of gas-lighting, the construction of railways, and the extended use of the steam-engine. The extraction of a portion of the pillars formed in the bord-and-pillar system of mining by a second working, and the more general adoption of the long-wall system, also commenced about this date, but could only be effected after a very partial and incomplete manner in fiery mines so long as dependence had to be placed on the insecure light afforded by candles and steel mills. The invention of the Davy safety lamp in 1815, and the introduction of panel-work and compound ventilation by Buddle, marked a distinct step forward in the development of the mining industry. About 1830 several shafts over 1000 feet deep were in operation, and about this time guides and caps were introduced into winding shafts.

The concluding chapter of the book brings the record up to 1835, and gives the suggestions made by the committee appointed to inquire into the causes and prevention of the accidents from explosions.

An account is published of the history of slavery in the Scotch collieries. The causes which led to the emancipation of the colliers are discussed.*

Bennett H. Brough † points out that the first volume of the *Trans-*

* *Edinburgh Review*, vol. clxxxix. pp. 119-148.

† *Transactions of the Institution of Mining Engineers*, vol. xvii. pp. 2-13.

actions of the Institution of Mining Engineers was published in 1889, and exactly a hundred years before that date the first volume of the *Transactions of a society with similar aims* was published. This society was founded by Ignatius von Born in Hungary, and included members from fifteen different countries. Among the members were James Watt, the inventor of the modern steam-engine; Matthew Boulton, his partner; Sir William Hamilton, the husband of Nelson's Emma; Goethe, the poet; Lavoisier, the illustrious French chemist; and many of the most brilliant investigators of the period. Owing to the death of the founder the society came to an end in 1791. The finances of the society were in a critical condition; its leading French members perished on the scaffold, and its other losses by death were enormous. It did excellent work during its brief existence, and the ideas embodied in its constitution were destined to be developed in a remarkable manner. The numerous Mining Institutes subsequently founded on similar lines became the repositories and guardians of the results of experiments and experience that would otherwise have been lost to the world.

J. W. Paul * gives a short account of the history of the Department of Mines and Mining in West Virginia.

R. Schneider † observes that the Lower Rhine Westphalian coal-field has made very great progress during 1898. The author gives a brief historical sketch of the progress coal-mining has made in this district during the present century.

Mine-Surveying.—For observing the daily variation of the magnetic needle, an observatory, similar to that at Bochum, has been installed at Waldenburg, in Lower Silesia. The cost has been borne by the coalmasters of Lower Silesia, and the observations have been entrusted to the surveying staff of the Hermsdorf Colliery.

Bennett H. Brough ‡ discusses the education of mine-surveyors in Prussia, and publishes a translation of the new Government regulations for the examination of mine surveyors.

An improved levelling-staff for mine-surveying purposes is described and illustrated by A. Fiala.§ It is stated to be a considerable improvement over those hitherto in use, admitting of being read off with great certainty and readiness.

* *Mines and Minerals*, vol. xix. pp. 228-229.

† *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlvii. p. 34.

‡ *Colliery Guardian*, vol. lxxvii. pp. 289-290.

§ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlvi. pp. 544-545; one illustration.

The Rating of Coal-Mines.—Edward Boyle * discusses the rating of coal-mines. It is suggested that any rating authority, desiring only to arrive at the true gross and rateable value of a colliery, should take into consideration all circumstances in connection with the premises, including the cost or value of the shaft and rateable machinery, the age of the mine, the quality and quantity of the coal, the rent paid under the lease, the rents recently obtained for similar coal under similar circumstances, the output, the prices obtained for the coals, and the expenses of producing and realising it.

G. Johnson † discusses reserve and sinking funds in relation to mining and manufacturing companies.

Mine Inspection.—The Prussian Minister of Trade has issued a report ‡ on the inspection of mines in England, France, and Belgium by representatives of the miners. The Commission reporting on the matter approve the arrangements obtaining in English collieries, but are not so favourably impressed with those obtaining in France. As regards Belgium, the system has only recently been introduced, and consequently experience is not yet available to show how it works.

Collieries in Great Britain.—Detailed descriptions have been published in the *Colliery Guardian* of a number of British collieries. The list includes the following in the Leicestershire coalfield: Brethby (vol. lxxvi. p. 829), Nailstone (vol. lxxvii. p. 58), and Moira (p. 106).

The collieries in the Nottinghamshire coalfield described are: Trowell Moor (vol. lxxvi. p. 921) and Wollaton (p. 965).

The collieries in the Derbyshire coalfield described comprise: Denby (vol. lxxvi. p. 1014), Hardwick (p. 1106), and Cresswell (p. 1199.).

The collieries in the Lancashire coalfield described comprise: Douglas Bank (vol. lxxvii. p. 246), Newtown and Meadows (p. 304), Tawd Vale (p. 335), Orrell (p. 381), and Pemberton (p. 488).

The collieries in the North Wales coalfield described are: Bersham (vol. lxxvii. p. 568) and Llay Hall (p. 610).

Collieries in the United States.—Illustrated descriptions of several American collieries have appeared. Amongst these are the

* *Transactions of the Surveyors' Institution*, vol. xxxi. pp. 143-180.

† *Iron and Coal Trades Review*, vol. lviii. pp. 144-145.

‡ *Zeitschrift für das Berg-, Hütten- und Salinenwesen im preussischen Staate*, vol. xlvii. pp. 1-43.

Tesla coal-mines, Alameda Colliery, California, by F. J. Horsewill,* the mines of the Northern Pacific Coal Company at Roslyn, and the mines of Kittitas county, Washington.† M. C. Schotz‡ deals with mine management, with particular reference to economical methods of working in the Kanawha Valley.

The mines at Carbonado, Wilkeson, and Burnett, in Pierce County, Washington, are also described,§ and J. E. Stockett|| gives an account of the haulage arrangements in use at the Cottonwood Mine, Cascade County, Montana.

In a paper read before the Ohio Institute of Mining Engineers, J. A. Ede described the Spring Valley collieries in Illinois. There are four shafts 300 to 500 feet deep. Apparatus is provided for weighing and screening four truck-loads of coal a minute. The small coal is taken to a washing plant capable of treating 400 tons a day. There is a good deal of iron pyrites in the coal, and the loss in washing is 15 per cent.

Andrew Roy¶ describes the coal-mines of Jackson County, Ohio. These mines have for a number of years past produced over 2,000,000 tons annually, but the output is now falling off.

IX.—COAL-WASHING.

Coal Screening and Washing.—In a paper read before the American Institute of Mining Engineers,** Charles C. Upham advocates the finer crushing of coal before sizing. He cites a number of experiments, one of which yielded the following results:—A sample of several tons of coal slack from the Pittsburg seam was washed in a trough-washer, one part being washed as received, the other crushed to particles $\frac{3}{16}$ in. and less in diameter. Analysis yielded the following results:—

| | Ash. | Sulphur. |
|----------------------------------|-----------|-----------|
| | Per Cent. | Per Cent. |
| Unwashed slack | 10.51 | 2.88 |
| Uncrushed washed slack | 7.97 | 2.23 |
| Crushed washed slack | 4.56 | 1.89 |

* *Mines and Minerals*, vol. xix. pp. 145-147.

† *Ibid.*, pp. 193-195.

‡ *Ibid.*, pp. 255-257.

¶ *Ibid.*, p. 254.

‡ *Ibid.*, pp. 225-226.

|| *Ibid.*, pp. 275-276.

** Buffalo Meeting, 1898 (advance proof).

This shows a considerable improvement for crushed coal as compared with uncrushed coal.

An illustration of the pit-head gear at the Deep Navigation pits, Treharris,* has appeared, together with a short account of the screening and cleaning plant.

Illustrations have appeared of Wrightson's design of table for picking coal.† It consists of an annular revolving plate over which is a spiral guide in the form of a trough for receiving the dirt. The table is inclined either to or from the centre according to the position of the feed and discharge.

A new slate-picker, the invention of A. H. Roberts,‡ was recently given a careful trial at Bernice, Pennsylvania. The picker consists of a series of 12-in. wheels with V-shaped faces, separated by washers $\frac{3}{8}$ in. thick and 3 in. in diameter. The wheels are $1\frac{1}{8}$ in. thick, and with the washers rotate with a shaft at sixty-five revolutions a minute. Above the wheels, in the shoot, are placed cast iron V-shaped plates, 12 in. long, with one end notched to receive the V-shaped end of the wheels. These receive the slate and turn it edgewise, so that it may drop through the space between the wheels into the bin below. Below the wheels in the shoot is a wrought iron plate notched to fit the wheels and receiving the coal as it passes over. The picker removes slate in a satisfactory manner, and does not become clogged.

A modified double-acting jig on the Oberegger system is described and illustrated by V. Waltl.§ The drying of jigged coal on grids formed of iron bars of wedge-shaped section is also referred to. These bars are so arranged as to let the water drop through them into a receptacle below, instead of running down the bars.

A plan and elevation of the coal-washing plant of the Coahuila Coal Company have been published.|| The coal from the mines is screened over diamond-shaped bars $1\frac{1}{2}$ inch apart. The screened coal is hand-picked and the small coal falls into a weighing hopper, and then is sized in a trommel, 4 feet in diameter and $8\frac{1}{2}$ feet in length. Nuts above 35 millimetres are jigged with or without crushing as is required. Small coal below 35 millimetres is passed to three revolving screens 4 feet in diameter and 11 feet long, where it is screened under

* *Colliery Guardian*, vol. lxxvi. p. 648.

† *Iron and Coal Trades Review*, vol. lviii. p. 200.

‡ *Anthracite Coal Operators' Association*, March 1899, pp. 16-17.

§ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlv. pp. 637-640, with sheet of illustrations.

|| *Iron and Coal Trades Review*, vol. lviii. p. 467.

a jet of water, and the various products are treated in jigs and classifiers. The analyses of the coal, washed coal, and coke are as follows:—

| | Raw Screening. | Washed Coal. | Coke. | Slate from Waste Box. |
|---------------------------------------|-------------------|-----------------|-----------|--------------------------|
| | Per Cent. | Per Cent. | Per Cent. | Per Cent. |
| Moisture | 1.40 | 0.79 | 0.43 | 2.22 |
| Volatile combustible matter | 19.79 | 20.30 | 1.39 | 15.76 |
| Fixed carbon | 60.25 | 66.80 | 83.47 | 30.96 |
| Ash | 17.33 | 11.61 | 14.24 | 50.12 |
| Sulphur | 0.85 | 0.51 | 0.82 | 0.93 |
| Phosphorus | ... | ... | 0.019 | ... |

H. L. Siordet * gives a description and some illustrations of various coal-washing machines, especial attention being given to the Robinson washer and the Scaife movable trough-washer.

The new coal-washing plant at the Blanzly Colliery is described by F. Graillet.†

Yield of an Anthracite Waste-Heap.—A. D. Smith ‡ describes the treatment and yield of an anthracite culm bank at Plymouth, Pennsylvania. The pile was originally about 900 feet by 700 feet and 30 to 45 feet high, containing the waste coal from the Reynolds Colliery accumulated between 1860 and 1880. A washing-plant was erected to treat it, with the following results:—

| | 1890 to June 1895. | | June 1895 to July 1898. | | Totals. | |
|--------------------------------------|--------------------|--------------|-------------------------|--------------|----------------|--------------|
| | Total. | Per Cent. | Total. | Per Cent. | Total. | Per Cent. |
| Cubic yards of bank washed | 295,000 | ... | 177,000 | ... | | |
| Nut coal made, tons | 2,326 | 4.1 | 819 | 1.3 | 3,145 | |
| Pea coal made, tons | 7,493 | 13.2 | | 9.9 | 13,649 | 11.5 |
| Buckwheat coal made, tons | 34,115 | | | 71.7 | 78,580 | |
| Rice coal made, tons | | | | 17.1 | 23,491 | |
| Totals | 56,820 | 100.0 | 62,045 | 100.0 | 118,865 | 100.0 |

* *Cassier's Magazine*, vol. xv. pp. 60-66.

† *Comptes Rendus de la Société de l'Industrie Minière*, 1898, pp. 204-212.

‡ *Engineering and Mining Journal*, vol. lxvii. p. 440.

Handling Coal.—Julius Kahn* describes the coal-hoists of the Calumet and Hecla Mining Company, which were erected in June and July 1898 at Kewenaw Point, Lake Superior. Travellers carry grabs, which work off a curved boom overhanging the boats, and lift the coal into trucks which run on trestles over the storage grounds.

G. W. Engel† describes the surface arrangements at the head of a slope at the Carbondale Colliery, Pennsylvania, where a curve of 30 feet radius and a central angle of 182° is used instead of switches for transferring the tubs.

The transportation of coal down the Ohio and the Lower Mississippi is described by J. H. Bartlett.‡

Briquettes.—Castellan§ describes the plant at the Plat-de-Gier Colliery, Loire, for handling the briquettes made from anthracitic coal-dust. These briquettes are in the form of balls weighing about 2 oz. each, and are made at the rate of ten tons hourly. They are stocked in a pile, to which they are carried by an elevated conveyer, and other conveyers in the ground serve to draw them off for loading.

* *Transactions of the American Society of Civil Engineers*, vol. xli, pp. 269-297; *Iron Age*, January 5, 1899, pp. 12-16, with illustrations.

† *Mines and Minerals*, vol. xix, pp. 152-153.

‡ *Minutes of Proceedings of the Institution of Civil Engineers*, vol. cxxxiv, pp. 334-351.

§ *Comptes Rendus de la Société de l'Industrie Minérale*, 1898, pp. 111-114.

PRODUCTION OF PIG IRON.

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I.—BLAST-FURNACE PRACTICE.

Charging Blast-Furnaces.—A. Wagner * illustrates a blast-furnace charging arrangement which consists in the application of a centrally-placed cylindrical tube within the furnace throat. The ore is charged around this.

Prevention of Loss of Gas when Charging.—With reference to O. Simmersbach's †, paper on this subject, showing the loss that occurs owing to the escape of gas when blast-furnaces are charged, and to the use of double-closing appliances for preventing this, Stähler ‡ points out that these are now becoming much more common in Germany. Thus Parry cones and outer covers are now in use, among other places, not only at the Burbach works, but also at the Metz & Co. works at Esch, and at two blast-furnaces at Differdingen, while the new blast-furnace at the Düdelinge works, and the two furnaces of the Mosel works at Maizières near Metz are also to have Parry cones and outer covers, steam being used for moving them.

T. Jung§ describes an early form of a doubly-closed top for a blast-furnace to prevent loss of gas in charging. This was in use in the Burbach district in 1876.

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlvi. pp. 677-678; three illustrations.

† *Journal of the Iron and Steel Institute*, 1898, No. II. p. 459.

‡ *Stahl und Eisen*, vol. xviii. p. 1005.

§ *Ibid.*, vol. xviii. p.

Analysis of Blast-Furnace Gas while Blowing In.—R. H. Sweetser* describes the operation of blowing in a blast-furnace in May 1897, and gives analyses of samples of the gases taken during the operation. Dimensions of the furnace as blown in are given as follows:—Height, 85 feet; diameter of bosh, 20 feet 6 inches; height of bosh above tuyeres, 17 feet; height of tuyere centre, 7 feet 3 inches; diameter of hearth, 13 feet 6 inches; stock line, 15 feet; sixteen 7-inch tuyeres.

The furnace was filled up to the tuyeres with wood, and with coke and ore charge up to the top. Cotton waste soaked with oil was placed in the tuyeres and used to start the fire just when the blast was turned on. The bell was closed half an hour later and the first sample of gas taken. The results were as follows:—

| Time. | Revolutions of Engine. | Blast Pressure. | Blast Temperature. | CO ₂ . | CO. | O. | CH ₄ . | H. | Total. | CO |
|--------------------|------------------------|-----------------|--------------------|-------------------|-----------|-----------|-------------------|-----------|-----------|-------|
| | | Pounds. | Fahr. | Per Cent. | Per Cent. | Per Cent. | Per Cent. | Per Cent. | Per Cent. | Ratio |
| May 26. | | | | | | | | | | |
| 12.26 p.m. . . | 15 | 0 | 300 | 10.8 | 16.2 | 0.6 | 1.1 | 6.66 | 35.36 | 1.50 |
| 1.33 „ . . | 15 | 0 | 320 | 3.2 | 27.0 | 0.0 | 4.0 | 2.10 | 36.3 | 8.4 |
| 2.44 „ . . | 18 | 0.8 | 450 | 2.8 | 28.8 | 0.0 | 4.2 | 0.0 | 35.8 | 10.22 |
| 4.05 „ . . | 18 | 1.0 | 500 | 3.0 | 28.6 | 0.0 | 4.2 | 0.0 | 35.8 | 9.55 |
| 5.13 „ . . | 24 | 1.6 | 425 | 3.6 | 28.4 | 0.0 | ... | ... | ... | 7.88 |
| 9.25 „ . . | 30 | 1.75 | 620 | 4.6 | 28.0 | 0.0 | ... | ... | ... | 6.08 |
| 10.45 „ . . | 30 | 2.25 | 450 | 5.8 | 28.4 | 0.0 | ... | ... | ... | 4.81 |
| May 27. | | | | | | | | | | |
| 11 a.m. . . . | 28 | 2.50 | 730 | 4.5 | ... | 0.1 | ... | ... | ... | ... |
| 2.45 p.m. . . | 28 | 3.75 | 860 | 5.0 | 26.8 | 0.0 | 7.4 | 0.0 | 39.2 | 5.20 |
| Normal { working } | ... | ... | ... | 12.5 | 25.3 | ... | 2.3 | 1.23 | 41.3 | 2.00 |

These results are also put into diagrammatic form.

Slips and Explosions in the Blast-Furnace.—F. B. Richards† gives photographic illustrations of the Claire Furnace, Sharpesville, Pennsylvania, before and five seconds after an explosion. The second photograph was taken by a photographer who accidentally happened to be by, and shows a huge cloud of dust-smoke covering the site. The furnace is 75 by 16 feet bosh diameter, and was working on a mixture of Lake Superior ores with a large percentage of fine Mesabi

* *Transactions of the American Institute of Mining Engineers*, Buffalo Meeting, 1898 (advance proof).

† *Ibid.*

ore. The charge had been slipping badly for some hours, when an explosion or great slip took place. No damage of any importance was done, and the furnace continued working.

Cooling Furnace Walls.—An arrangement of water-pipes for cooling furnace walls, devised by A. P. Gaines, is being introduced in one of the South Pittsburg furnaces. A pipe with closed ends tapering from $3\frac{1}{2}$ inches and 7 feet long is sunk at an angle of 75° into the wall. A central pipe passes through the top end and leads water to the bottom, whence it escapes through the annular space between the pipes and passes away by a side pipe at the top. The appliance is simply placed in a hole bored in the walls whenever a cooling action is required.*

Fluor-Spar in the Blast-Furnace.—R. Moldenke † discusses the use of fluor-spar in the blast-furnace, and thinks that under some circumstances it might have some advantages in spite of its higher cost as compared with limestone, as is the case in cupola practice. Within moderate limits it should not harm the lining, whilst it has a dephosphorising and possibly also a desulphurising action. It renders slag more liquid, but it must not be forgotten that a certain amount of slag is requisite to keep the furnace in proper working order. The greater fluidity of the slag enables the furnace to be run at lower temperatures, and this in turn means lower silicon in the iron. In the Shenango Valley recently a severe case of scaffolding was cured by blowing powdered fluor-spar through the tuyeres.

Zinciferous Ores in the Blast-Furnace.—According to W. W. Taylor,‡ the iron ores of the Oriskany period smelted in the western counties of Old Virginia usually contain zinc. The amount seldom exceeds 0.10 per cent., but it often occasions great trouble with the furnaces using these ores. Under normal conditions most of the zinc deposits on the cooler parts of the furnace walls as “cadmia,” while the remainder is carried over into the stoves and flues as dust, which can easily be removed. The “cadmia” contains: Metallic zinc, 73 per cent.; silica, 2.5; ferrous oxide and alumina, 3.0, and it forms a valuable by-product. With hard driving and low fuel consumption,

* *Iron Trade Review*, December 8, 1898, p. 9.

† *Ibid.*, January 5, 1899, p. 11.

‡ *Ibid.*, March 30, 1899, p. 7.

the accumulation on the walls in the top of the furnace seriously interferes with the working. If it breaks away and falls into the furnace, the iron changes from grey to a silvery, brittle product. At the Longdale furnaces the ring of zinc deposit, weighing as much as 12 tons, is removed occasionally by allowing the stock to settle and cutting it out in sections.

Tuyeres.—In some notes on tuyeres J. M. Hartman* shows the necessity for very perfect circulation of water at the nose of the tuyere to prevent its being burnt out. Pure copper castings are generally too soft for tuyeres, and yellow metal is preferred, as not being so liable to crack as iron or copper. The size of the tuyere must be proportioned to the amount of air, so as to obtain the requisite penetration of the blast, but this factor is also affected by the nature of the stock, and requires careful watching to prevent the blast striking back, and to prevent the accumulation of dust or of pockets of molten metal. Oval tuyeres and other forms are also considered, and it is held that their use will become more extended.

B. F. Fackenthal† sketches the history of the tuyere in the blast-furnace. One of the earliest furnaces in America was that at Durham, Pennsylvania, which was charcoal-fired and blown through a single tuyere with bellows. Even down to recent years many charcoal furnaces only used a single tuyere. In many of the early furnaces wrought iron hollow-welded tuyeres were used, and this construction followed the wrought iron coil tuyeres, which subsequently came into general use again. Cast iron hollow tuyeres were also used. Later on bronze tuyeres came into use. The gradual increase in the number of tuyeres is noticed, and reference is also made to the use of rectangular tuyeres and to bosh-cooling appliances.

Hot-Blast Stoves.—Illustrations have appeared‡ of a new hot-blast stove erected at the Eston Steelworks. The chequer-work is built of bricks shaped in plan like two crosses placed together(++) , so as to allow of proper bonding, and is supported on grids. The combustion chamber is of segmental form, and the lower part of the stove is divided by cast iron partitions, which support the checker grids, and

* *Transactions of the American Institute of Mining Engineers*, Buffalo Meeting, 1898 (advance proof).

† *Ibid.*

‡ *Engineer*, vol. lxxxvii. p. 411.

contain doors which can be opened or closed from the outside to control the circulation of gas.

According to J. H. Harrison,* the first hot-blast stove of the Ford and Moncur type was erected in the Middlesbrough district in 1896, and there are now 160 of these stoves at work in this country. The shell and lining of the Ford and Moncur stove is much the same as an ordinary Cowper stove, but the combustion chamber is rectangular, and stretches right across the centre of the stove in plan, thus dividing it vertically into a combustion chamber in the centre, the upper part of which is subdivided into comparatively small rectangular passages, and a chamber filled with chequer-work on either side of it. These two chambers are each again divided in the centre by a brick wall, extending from the floor of the stove to the dome, against which it is tightly built. Thus in plan the stove is divided into four separate compartments, pairs of which directly communicate at the top, and the two pairs also communicate at the lowest point of the small rectangular passages in the combustion chamber. Below the grids each of the four compartments communicates with the smoke flue under the combustion chamber by means of the rectangular wing valves, each of which can be closed or opened from the outside of the stove by hand-wheels and screws. This smoke flue opens into a chimney valve of the usual type, but having fixed between it and the shell a circular butterfly valve of the same diameter as the chimney valve, but with its spindle slightly out of centre, and called the instantaneous valve. There are also four manholes at the bottom, opening under the grids, and one in the centre of the dome top, giving access to the inside of the stove when desired. The size of stove which has been chiefly adopted is seventy-two feet high to top of dome and twenty-six feet diameter inside of shell, but these sizes have been very much varied. The working of these stoves and their advantages are fully described, and an account is given of the improved arrangements for cleaning them as installed at one of the West Coast blast-furnace plants. In these all the valves are outside the stove and blow-out valves are arranged to clear out the dust.

Hot-Blast Valves.—J. Robinson† gives his own experience of hot-blast valves of various types, including simple disc valves, air-cooled disc valves, water-cooled valves used with Ford and Moncur

* *Proceedings of the Cleveland Institution of Engineers*, 1898, pp. 45-71.

† *Journal of the West of Scotland Iron and Steel Institute*, vol. vii. pp. 77-90, with two plates.

stoves and with Whitwell stoves. Finally, a valve with a drum body and water-cooling both for the valve and seat designed by himself is described and illustrated in detail. Several valves of this design have lasted well.

Blowing Engines.—An illustration has appeared* of a pair of vertical cross compound blowing engines made for the North-Eastern Steel Company's works, Middlesbrough. They are designed to supply air at 15 lbs. pressure with a steam pressure of 70 lbs. and exhaust of 10 lbs. at 50 revolutions. The air cylinders are 84 inches and the steam cylinders 48 and 84 inches in diameter with a stroke of 54 inches. The slide valves are double ported with Meyer expansion valves, varying the cut-off from $\frac{3}{16}$ to $\frac{7}{16}$ of the stroke. Dimensions are given of the principal parts.

Illustrations have appeared† of some new blowing-engines, built in Bohemia for the Hernádthai Works, Krompach. The duty required is a maximum supply of 28,500 cubic feet of air at $10\frac{1}{2}$ lbs. pressure and $52\frac{1}{2}$ revolutions per minute, and a maximum consumption of 14.88 lbs. steam at $7\frac{1}{2}$ atmospheres effective pressure per indicated horse-power. The engines are of the two-cylinder receiver compound class, with horizontal steam and air cylinders coupled direct, and Corliss gear for both cylinders. The leading dimensions are: Diameter of high-pressure cylinder, 35.43 inches; low pressure, 54.34 inches; blowing cylinder, 76.78 inches; and stroke, 55.12 inches. The results of a trial and indicator diagrams are given.

In another paper, A. von Ihering‡ observes that two blowing-engines were ordered for the Hernádthai Ironworks in Hungary in 1895. These were required to fulfil a number of requirements which he mentions, and on completion were put in erection at the Company's works at Krompach in 1896. They had been made at Schlan, in Bohemia. The author fully illustrates and describes these engines, which were started at the end of August 1897, and have given satisfaction.

H. W. Jarvis§ deals with various methods of cooling condenser water, and gives especial attention to Klein's apparatus, which is used in the Middlesbrough district.

* *Engineering*, vol. lxvii. p. 11, with plate.

† *Stahl und Eisen*, vol. xviii. pp. 929-934.

‡ *Zeitschrift des Vereines Deutscher Ingenieure*, vol. xlii. pp. 1153-1156, with 5 illustrations in the text and 1 plate.

§ *Proceedings of the Cleveland Institution of Engineers*, 1899, pp. 76-99.

Casting-Machines.—A fully illustrated description has appeared of the Uehling casting and conveying machine which was recently erected at the works of the Millom & Askam Hæmatite Iron Company, Limited. It consists essentially of two strands of travelling moulds, supported on a steel structural frame; shoots to convey pig from the moulds to the conveyer; the cooling conveyer travelling in a water tank, and shoots to convey the pig iron from the conveyer to the railway waggons. In addition there is a steam-engine, with the necessary shafting and gearing, and an air compressor and receiver. The machine at Millom is a standard size machine—that is, it consists of two strands of travelling moulds.*

The Utilisation of Blast-Furnace Gases.—H. Allen † deals with the utilisation of blast-furnace gases in the gas-engine. Of the total heat generated by the coal 51·6 per cent. is used in the furnace, 4·4 per cent. escapes as sensible heat, 11 per cent. is used for heating the blast, and the remaining 33 per cent. may be used for firing boilers or in gas-engines. The poorest quality of gas that the author has had the opportunity of considering contains 25 per cent. of carbonic oxide, and it is found that this, with its accompanying but small proportion of hydrogen derived from the decomposition of the moisture in the air-blast, is capable of giving the necessary explosive force in a gas-engine, providing that the amount of compression of the mixed air and gas has been carried sufficiently high. It has been estimated that when raw coal is the fuel employed in the furnace, there will be about 130,000 cubic feet of gas evolved for each ton of coal charged into the furnace. When coke is the fuel used, the quantity of gas is much larger, amounting to from 170,000 to 180,000 cubic feet per ton of coke charged. It may be taken that to produce the power of one indicated horse-power by means of boilers and steam-engines, even under favourable conditions, requires from 600 to 700 cubic feet of gas evolved from coke-fed furnaces, while from 100 to 150 cubic feet, when used explosively in a gas-engine cylinder, will generate the same power. The ratio in favour of the latter system is thus nearly six to one. The author then gives a number of calculations, the object of which is to arrive at the chemical composition and thermal value of the best and poorest possible qualities of blast-furnace gas, and to do this there is assumed, first, a case where only coke is being charged

* *Iron and Coal Trades Review*, vol. lvii. pp. 912-914.

† Paper read before the South Staffordshire Institute of Iron and Steel Works Managers, December 10, 1898.

and no iron made, and second, where 17 cwt. of coke, containing 90 per cent. carbon and 10 cwt. of limestone, are consumed in the production of one ton of pig iron, having a composition as follows:—

| Iron. | Carbon. | Silicon, &c. |
|-------|---------|--------------|
| 94 | 4 | 2 |

The thermal value per cubic foot is found to be 121·84 British thermal units in the first case, and 66·89 in the second, but the actual thermal value of blast-furnace gas is above this, being 82·5 at the South Chicago Works, and 137 at Messrs. Hickman's furnaces, where four parts of coke to one of coal are used. The percentage composition by volume of these four gases is given as:—

| | | | | |
|------------------------------|-------|-------|-------|-------|
| Carbonic anhydride | | 16·51 | 12·00 | 5·88 |
| Carbonic oxide | 33·84 | 19·76 | 25·50 | 37·50 |
| Hydrogen | 1·38 | 1·36 | 1·36 | 6·12 |
| Nitrogen | 64·78 | 62·37 | 61·14 | 50·50 |

In coke-fed furnaces the thermal value of the effluent gas is usually not lower than 100 British thermal units. The advantages of the gas-engine system are then dealt with at some length.

F. Toldd* observes that the utilisation of blast-furnace gas as a motive power in gas-engines is objected to by many as being never possible on various grounds which the author enumerates. These include the low calorific value of the gas, the quantity of dust it carries with it, the variation in its pressure, the difficulty of igniting such large quantities, and generally other engine difficulties, such as the increased cylinder dimensions, &c. With some of these the author deals. Why, he asks, cannot Von Ehrenwerth's proposal, made so far back as 1883, to regenerate the gas be adopted? A richer gas would result, and the dust which would be in the regenerated gas is certainly not more difficult to separate than that which comes from the blast-furnace. Indeed the regenerating plant would in part act as a scrubber. It was calculated by Von Ehrenwerth that the absolute heating effect of a gas of the following percentage composition:—

| | | | | |
|-------|-------------------|-------------------|------|-------|
| CO. | CO ₂ . | CH ₄ . | H. | N. |
| 24·23 | 20·60 | 0·38 | 0·21 | 54·58 |

was 704·26 calories. This gas, when completely regenerated, would contain—

| | | | | |
|-------|-------------------|-------------------|------|-------|
| CO. | CO ₂ . | CH ₄ . | H. | N. |
| 42·42 | 0·00 | 0·21 | 0·15 | 57·22 |

* *Stahl und Eisen*, vol. xviii. pp. 1140–1141.

and would possess a calorific power of 1098·47 calories. The same gas regenerated in practice contains—

| CO. | CO ₂ . | CH ₄ . | H. | N. |
|-------|-------------------|-------------------|------|-------|
| 34·87 | 8·37 | 0·28 | 0·18 | 56·30 |

and has the calorific value of 936·54 calories.

Hiertz gives the composition of blast-furnace gases in two instances—

| | CO. | CO ₂ . | H+CH ₄ . | N. | H ₂ O. |
|-----|-------|-------------------|---------------------|-------|-------------------|
| I. | 27·90 | 13·90 | 1·02 | 50·12 | 7·01 |
| II. | 23·98 | 16·78 | 1·07 | 51·51 | 6·66 |

the absolute heating effect of I. being 1166, and of II. 1046 calories. These would be nearly half as effective again if they were regenerated. Any moisture present in the gas when it leaves the blast-furnace would be converted into hydrogen and carbon monoxide in the regenerating plant, while the use of steam, too, in this latter would enable the hydrogen percentage of the regenerated gas to be increased at will.

The Separation of Carbon in Blast-Furnaces.—In a paper read before the Chemical Society at Aix-la-Chapelle, E. F. Dürre * considers the conditions under which the separation of carbon occurs in blast-furnaces. Two modes of separation are possible. In one of these the carbon would result from the dissociation of carbon monoxide into carbon and carbon dioxide, and in the other by the action of iron oxide and iron on the furnace gases. The first of these necessitates a high temperature, and probably takes place in the hot gases at the sides of the furnace when coming in contact with freshly charged ores, &c. The other method of deposition is stated to take place at temperatures of from 300° to 400° C., if the ore has not been completely reduced. It is somewhat difficult to understand in this latter case how both the metallic iron and the iron ore can produce this decomposition of the carbon monoxide with the deposition of carbon. Lürmann has attributed the decomposition of the gases and the deposition of carbon in the bricks used in the furnace construction to the action of manganese oxide, due to the decomposition of pyrites in the brick material. The author refers to the effect this carbon has on the bricks, quoting instances at Mühlheim-on-the-Ruhr and elsewhere. He next refers to the influence such deposited carbon has in causing explosions in blast-furnaces, leading, as it may, to these hanging up, and to the collection

* *Chemiker Zeitung*, vol. xxii. p. 309; *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlv. p. 672.

of explosive gas mixtures. The effects observed in connection with these leave no doubt as to the deposition of such carbon in the upper portion of the blast-furnace.

Coal Consumption in Blast-Furnaces.—According to the Home Office returns, the principal iron-making districts compare in their coal consumption as follows :—

| District. | Make of Pig Iron. | Coal Consumption. | Average Tons of Coal per Ton of Pig Iron. |
|-----------------|-------------------|-------------------|---|
| | Tons. | Tons. | |
| Cleveland | 3,197,641 | 6,124,033 | |
| Scotland | 1,136,507 | 2,419,671 | 2·1 |
| West Cumberland | 819,475 | 1,603,215 | 1·9 |
| Lancashire | 706,893 | 1,322,901 | 1·8 |
| South Wales | 523,733 | 923,784 | 1·7 |
| North Stafford | 242,688 | 436,682 | 1·8 |
| South Stafford | 324,059 | 683,756 | 2·1 |

The Use of Peat as Fuel in Blast-Furnaces.—K. J. Reiner * has endeavoured at the Kulebaki Ironworks to use peat as fuel in the blast-furnace. It was first coked, 180 parts of the wet peat yielding 40 to 50 parts of the peat charcoal, better results being obtained in spring than in winter. This peat charcoal contained per cent. :—

| | | |
|---------------|------------------|------|
| Fixed Carbon. | Volatile Matter. | Ash. |
| 81 | 12 | 7 |

and it had the specific gravity 0·6. This peat charcoal in appearance closely resembled ordinary coke from bituminous coal. It had a graphitic lustre, did not break up, was non-hygroscopic, and had a metallic ring when struck. The cost of production at the works amounted to 22·58 kopecks per pood, and per pood of pig iron from 20·07 to 25·6 kopecks; while the cost per pood of pig iron amounted in the case of charcoal to 25·9 kopecks. At present practically no attention is paid to the peat deposits in the iron-making districts of Russia.

Lignite for Iron-Making.—Tests of lignite as fuel in making pig iron have just been made in Texas with satisfactory results. The

* *Rigaer Industrie-Zeitung*, vol. xxiv. p. 237.

fuel first used consisted of 50 per cent. of lignite and 50 per cent. of charcoal; and the proportion of lignite was increased until 100 per cent. was used.*

Use of Petroleum for Smelting Iron Ore.—Chatisof † deals with the use of petroleum for smelting iron ore, in view of the richness of the Caucasian deposits and the scanty supply of suitable solid fuel. There are, however, certain difficulties shown to exist by experiments made with oil as fuel, and it is suggested that the Association of Naphtha Producers should provide for experiments on a larger scale to settle the question.

New American Blast-Furnaces.—The two new blast-furnaces that are to be erected at the Ohio Steel Company's works at Youngstown are to be 105 feet in height and 23 feet wide at the boshes. The hot-blast stoves are also to be 105 feet high. A daily out-turn of 1200 tons of pig iron is anticipated.‡

A general description of the works of the Illinois Steel Company has appeared,§ and contains particular reference to the blast-furnaces and steel plant at the South Works, Chicago. A general plan is given to show the arrangement, and several illustrations are appended. There are eight furnaces in two groups of four, of which the first set, built in 1880–81, are 75 feet high, with 17½ to 19½-foot boshes, and the second set, built in 1890, are 85 feet high, with 19½ to 20¾-foot boshes. The first set have each four Whitwell-Foote stoves, 21 by 67 feet, and the latter four Massick & Crookes' stoves, 22 by 77 feet. Excess gas is used for firing boilers. Coke is loaded into the charging-trucks from bins, and ore by hand or a steam-excavator. Each furnace has a double vertical hoist and a brick casting-house. Dust from catchers placed in the flues is mixed with lime and briquetted. Slag is run into Weimar ladles, which are emptied into long beds, the slag forming layers 2 to 3 inches in thickness. When sufficient has accumulated, it is loaded into railway waggons by a steam-excavator and used for ballast, road-metal, and concrete. Slag wool is also made in a special plant.

* *Colliery Guardian*, vol. lxxvii. p. 487.

† Paper read before the Technical Society of Baku, February 1899, through the *Engineer*, vol. lxxxvii. p. 390.

‡ *Stahl und Eisen*, vol. xviii. p. 1012.

§ *Engineer*, vol. lxxxvi. pp. 609, 633.

The Evolution of the Blast-Furnace.—A. H. Sexton * traces the evolution of the blast-furnace from the earliest times up to the present era. The early forms of native furnaces for the manufacture of wrought iron are described as they developed into the bloomeries and the Catalan forge. As these grew larger, an increased amount of cast iron was made, but when that material was first used and by whom is unknown. The first furnace for the manufacture of cast iron of which the date is known was erected in Belgium in 1340, but it was many years before it became general, and about a century before it crossed to Great Britain. The blast-furnace of that day was very different from that of the present day. These furnaces were small structures, usually square in shape and 20 feet or so in height. They were built of solid masonry, so that they were nearly as wide as they were tall. The blast was supplied by leather bellows, usually driven by water power. The output at Cuckfield, Sussex, was about eight tons per week for each furnace, twenty-four loads of charcoal being used for eight tons of iron. As the casting was once in the twelve hours, each cast was about thirteen or fourteen hundredweights.

The smelting of iron in the blast-furnace now became very general and the demand increased. As charcoal was the fuel, the works were set down where there was plenty of wood. In England it was among the woods of Sussex and Kent. In Scotland the first furnace seems to have been erected at Letterewe, Ross-shire, in 1607; and later there were erections at Furnace, Lochfyne, and at Bunawe on Loch Etive, the last only having been blown out so recently as about thirty years ago.

No further improvements were made till the last century. The size of the furnace was somewhat increased, but owing to the friability of the fuel they were necessarily small. Still the iron industry flourished, and furnaces and forges were erected all over the country, until the charcoal supply showed signs of extinction, and then coal came into use. Later developments are briefly traced.

J. Tomkins † gives a general account of the extraction of iron from its ore in the blast-furnace. The nature of the ore, its treatment by calcination, the construction of the furnace, fuel and fluxes are briefly dealt with.

In a continuation of his "History of Iron," L. Beck ‡ discusses the

* Paper read before the Philosophical Society of Glasgow, January 18, 1899.

† Paper read before the Derbyshire Metallurgical and Engineering Association, through the *Colliery Guardian*, vol. lxxvi. p. 622.

‡ *Geschichte des Eisens*, vol. iv., Brunswick, 1899.

history of this metal during the first half of the present century. He divides this period into several subdivisions, treating each of these separately. The period now considered is marked by the struggle between coke and charcoal, as fuel for iron smelting purposes, and the victory of the former. The Emperor Napoleon I. observed that money and iron were necessary to secure peace, and he favoured and supported the iron industry in France and in the countries he had conquered, but the constant warfare prevented any great degree of progress resulting from his efforts. Lasting peace only commenced in 1816, but the nations of Europe were then in a state of exhaustion, and in Germany the division of the empire into forty different states, with the various customs, and other difficulties resulting from this subdivision, still prevented any great progress being made. The result was that the fruits of the victories of Leipzig and Waterloo fell chiefly to the share of the United Kingdom. After the war the progress made by the iron trade of the United Kingdom was relatively extremely rapid. About ten years after the peace, railways began to be introduced, and these only became possible owing to the great progress which the iron trade had made, the production having largely increased, and suitable kinds of metal being obtainable, and at a reasonable price. It was not till this became possible that railway construction became practicable. The author deals with the various early efforts at rail-making, illustrating the rails that were produced.

The blast-furnaces were first built with heavy rough walling, and frequently with a rectangular hearth and one or two tuyeres. The desire for an increased out-turn led to larger furnaces being built, and this in turn led to changes in the furnace construction. Thus as early as the third decade of the century, a furnace was built at Dowlais which was circular in section, and in which the heavy rough walling was replaced by the use of iron bands. This furnace made 105 tons of pig iron a week, a quantity which at that time was thought enormous, although it was only provided with two tuyeres. The hearth even in this furnace was still surrounded with heavy walling which carried the shaft. Subsequently this, too, was abandoned, with the result that the use of more tuyeres became possible. One of the first furnaces provided with a free hearth and a shaft carried on iron columns was erected by De Wendel in 1838 at Hayingen, but this furnace still only had two tuyeres. An illustration of it is given. Although the modern form of blowing-engine was originated and introduced in the eighteenth century, other types

were still in use, as the author shows by instances that he mentions. These, however, were gradually all replaced by the present type.

The history of the hot-blast is next dealt with, and the introduction of the use of gaseous fuel. In the beginning of the forties gas-producers were erected at Wasseraufingen, Königshütte, and a number of other places.

In foundry practice considerable progress had been made at the commencement of the century. This was due in part to the requirements of warfare, and to the increasing use of machinery since the discovery of the steam-engine. The United Kingdom was in this respect, too, again to the fore, and Karsten, writing in 1816, said that all the chief improvements were due to England. In 1804 Samuel Lucas patented malleable castings, and the process described is still largely identical with that still in use. On the Continent the process is believed to have been first introduced in 1829 at Traisen, near Lilienfeld, in Austria. In Germany it was not introduced before 1840, when it was employed at Solingen.

The conversion of pig iron into malleable iron is dealt with in much detail, as well as the manufacture of crucible steel. In 1811 Friedrich Krupp commenced its manufacture near Altenessen, and so originated what has since developed into the most renowned steelworks of this century. In 1826, when the original founder died, the works had only four regular workmen. In 1832 the works employed ten men, but the sale of a patent in England gave funds by which a large portion of the debts on the works were paid off. In 1848, however, the political unrest that then existed nearly brought the works to an end. In 1849 a 3-pounder gun made at this works was successfully tested at Berlin, and from this time onwards the works began to be successful.

The progress in the construction of the various mechanical appliances used in ironworks is shown, and the introduction of the steam-hammer by Nasmyth in 1839 specially referred to. The first steam-hammer was not constructed in England, however, but in France at the Creusot works. The owner of this works when on a visit to England is stated to have made a copy of Nasmyth's sketch, and to have built such a hammer immediately on his return to France, where Nasmyth was astonished in 1842, when he visited the Creusot works, to see it in use. He subsequently built a 30-cwt. steam-hammer at his own works, and the wonderful degree of accuracy with which it could be worked attracted much attention. In Germany the first steam-hammer was put into work on January 13, 1843, at Königin-Marienhütte. Rolling-

mills were introduced on the Continent when the puddling process was introduced.

Some interesting details dating from the year 1823 are published by Zintgraff* which relate to the methods employed in those days for damping down charcoal blast-furnaces, and the practical observations made in connection with this.

Old Iron Works in Brazil.†—The Ypanema Iron Works, in the State of San Paulo, Brazil, date from 1590, in which year two Catalan forges were set up by Affonzo Sardinha. Work was carried on regularly until 1629, when it was abandoned. In 1760 a new furnace was built, with leathern bellows and a trip hammer, but was abandoned. In 1801 a blast-furnace, with hand machinery to furnish the blast, was erected, but gave no results. In 1811 the Government took charge and contracted with certain Swedes to erect Stüicköfen and make bar iron. In 1814 four of these furnaces were in operation, but the ore proved so refractory that the yield was only one ton of iron for forty-one of charcoal. Blast-furnaces were then erected, with proper blast appliances, and the system now employed was gradually developed. Pig iron and bar iron are made at these works, but the quality of both is inferior, owing to the poor quality of the ore.

Grading Pig Iron.—W. Phillips ‡ returns to the subject of grading pig iron by its fracture, and advocates the more extended use of analysis. He suggests that instead of the present thirteen grades there be used only six, and that in grading iron the three elements of silicon, combined carbon, and sulphur be used, with the understanding that for certain purposes the phosphorus also be included. These six grades might be as follows:—

| | Silicon. | Combined Carbon. | Sulphur. |
|---------------|------------|------------------|--------------|
| Silvery irons | 5 to 6 | 0.10 to 0.30 | 0.01 to 0.04 |
| Soft irons | 3 to 5 | 0.20 to 0.50 | 0.01 to 0.05 |
| Foundry irons | 2 to 3 | 0.30 to 0.90 | 0.01 to 0.07 |
| Grey forge | 1 to 2 | 0.40 to 1.25 | 0.04 to 0.09 |
| Mottled | 0.6 to 1 | 0.50 to 1.80 | 0.06 to 0.11 |
| White | 0.1 to 0.6 | 1.0 to 2.50 | 0.08 to 0.30 |

* *Stahl und Eisen*, vol. xviii. pp. 1086-1090.

† *Brazilian Bulletin*, December 1898, through the *Engineering and Mining Journal*, vol. lxvii. p. 201.

‡ Paper read before the Pittsburgh Foundrymen's Association, December 27, 1898, through the *Iron Trade Review*, vol. xxxi., December 29, pp. 8-10.

About eighty answers have been received * in reply to a circular issued to foundrymen asking their opinions on the purchase of pig iron by analysis and on the methods of grading. Purchase on analysis appears to be adopted by about 64 per cent. of those who reply, whilst 20 per cent. do not use analysis. The opinions as regards grading vary widely. Many desire to see the iron graded by its chemical composition, in some cases by all the elements, but more usually by the silicon and sulphur.

II.—CHEMICAL COMPOSITION OF PIG IRON.

Manganese in Iron Ores and Pig Iron.—R. R. Tatlock and R. T. Thomson † discuss the question as to what becomes of the manganese in the blast-furnace. Ores are divided into three kinds, the siliceous and the limey ores, and those of mixed character containing both silica and lime in notable amount, and a table is given showing the relative proportions of iron and manganese in the general run of these ores. The percentage of manganese in Scotch hæmatite pig iron from 1873 to 1889, according to a large number of analyses, varied from 0·80 to 1·75 per cent., with an average of about 1·2 per cent., and there does not appear to be any gradual rise in the manganese during this period, although there may have been a slight rise in recent years. In English hæmatite pig iron as made twenty years ago, there was found only some 0·25 per cent. of manganese; but since the use of the more manganiferous Spanish ores became more common, the manganese has risen to 1 per cent., and even above that. As regards the Scotch common irons containing phosphorus in large proportion, it has always been usual to find from 2 to 3 per cent. of manganese in them. One trial gave a consumption of 34 cwts. of ore, with a production of 20 cwts. of pig iron and 8·28 cwts. of slag. The manganese in these materials was as follows :—

| | In Ore. | In Pig Iron. | In Slag. |
|--------------------|---------|--------------|----------|
| Per cent. . . . | 1·584 | 1·98 | 1·75 |
| Weight in lbs. . . | 60·32 | 44·35 | 16·23 |

The amounts do not tally by about a quarter of a pound, but this is

* *American Manufacturer*, vol. lxiv. pp. 31, 55, 79, 99, 132, 160, &c.

† *Journal of the West of Scotland Iron and Steel Institute*, vol. vi. pp. 55-76.

within the limits of error. It shows that 73·2 per cent. of the total manganese in the ore passes into the metal and 26·8 goes into the slag. Analyses of slag and various particulars calculated for other furnaces are given, showing that 24·7 per cent. on the average passes into the slag in Scotch furnaces, and 28·9 in English furnaces. This may be partly accounted for by the more basic nature of the Scotch slags, but the temperature may also have some influence. About a quarter of the manganese calculated on the average of 92 parts of iron in the pig iron goes into the slag when 8·28 cwts. of slag are made per ton. This amount may be increased by increasing the volume of the slag, or *vice versa*, but in Scotch practice it would be difficult to make iron with less than 1·5 to 2 per cent. of manganese.

Ferro-Silicon.—According to G. de Chalmot,* ferro-silicon containing 11 to 13 per cent. of silicon has been made in the blast-furnace and used in the manufacture of iron and steel, but the percentage of silicon can only be increased by recourse to the electric furnace. In this way alloys with as much as 46 per cent. of silicon are made, but above 50 per cent. the silicon separates out in small black crystals. Silicides with 25 to 50 per cent. appear to consist of a mixture of Fe_3Si_2 and FeSi_2 . The former crystallises out from compounds containing about 27 per cent. of silicon. Ferro-silicon with 26 per cent. can be melted in a brass furnace; when 32 per cent. is reached a blast is required, and above that point the electric furnace is required for fusion. When melted in a cupola a large proportion of the silicon is lost by oxidation. Low grade silicides cast well, but higher grades crack and form blowholes. Above 30 per cent. the compounds are non-magnetic. In the manufacture of rich ferro-silicon coarse river sand is mixed with finely-ground coke and iron ore, and is treated in a continuous electric furnace.

Kladno Pig Iron.—F. Toldt† draws attention to an erroneous statement that Kladno pig iron contains over 1 per cent. of sulphur. As a matter of fact, numerous analyses have shown the percentage to be at present rarely in excess of 0·1.

* *Journal of the American Chemical Society*, vol. xxi. pp. 59-66.

† *Stahl und Eisen*, vol. xviii. p. 1141.

III.—*BLAST-FURNACE SLAGS.*

Slag Cement.—It is stated that the Illinois Steel Company are erecting plant at their North Chicago works for the manufacture of slag cement. The process to be used is as follows :—A stream of slag is granulated in a tank under the influence of a powerful jet of water, and the granulated slag is passed through rotary driers and ground in Griffin mills. The ground product is further ground, and incorporated with lime, &c., in Davidsen mills, which are horizontal revolving cylinders 16 feet long and 4 feet in diameter, partly filled with egg-shaped flints 1 to 2 inches in diameter.*

IV.—*FOUNDRY PRACTICE.*

Modern Cupola Practice.—Further numbers of a series of articles† on some variations in cupola design deal with cupolas attempting economy by alteration of their vertical section. Amongst the forms treated are Ireland's cupola, the Gerhardi-Ireland cupola, Gmelin's cupola, the Grandall cupola, the Groves cupola, and the Troy Steelworks cupola. Of the cupolas employing hot-blast or utilising the escaping gases, mention is made of the Brown-Bayley cupola, the Tittl and Erndt cupola. Cupolas employing induced draught are Heaton's cupola, the Hilton cupola, the Woodward cupola, Krigar's cupola, the Herbertz cupola.

Cupolas fired by gas include Dufrene's cupola, Bramhall's cupola, Krigar's double-shaft cupola, and the Riley cupola combined with an open-hearth furnace.

Cupolas arranged for the injection of oil, coal, or other substances include those on the systems of Batty, Voisin-Bichon, Herdlitschka, Jones, and Ibbruger.

E. Kirk‡ discusses the question of blast and tuyeres in cupola practice.

Randol§ deals with the use of natural gas in the foundry, Tesson||

* *Iron Age*, March 9, 1899, p. 5.

† *Iron and Coal Trades Review*, vol. lviii. pp. 378, 424, 456, 501, &c.; *Journal of the Iron and Steel Institute*, 1898, No. II. p. 478.

‡ *Iron Trade Review*, February 9, 1899, pp. 12-13; February 16, p. 12.

§ *American Machinist*, 1899, pp. 230-231.

|| *Portefeuille Économique des Machines*, 1899, pp. 43-46.

with the preparation of large castings, and T. Ehrhardt * with foundry appliances.

Cupola Practice in China.—A description has appeared † of a cupola run at Huang Kiao. The cupola was in three sections and was blown by bellows worked by two or three men. One man stirred the charge, and when it was melted down the two top sections of the cupola were removed, leaving the molten iron in the lower section. The iron was cast into ploughshares, and as fast as they set they were turned out and the moulds repaired. The charge consisted of 50 catties of iron and 20 of fuel, and four melts were made daily.

Chilled Rolls.—According to E. D. Nicholson, ‡ all the best chilled rolls are made in Staffordshire from cold-blast iron produced in that county and in Shropshire. Rolls made in other places are more liable to breakage or to shelling or “spawling.” A chilled roll for hot-rolling should have sufficient strength when heated to do its work; a clear hard surface free from all pin-holes, cracks, or other blemish; a depth of chill that will allow of its being turned, say, every week until it has done a fair quantity of work; and the chilled portion must not be of such a nature as will shell off under fair treatment before the roll has worn out; on the other hand, it must not be too soft and wear out too soon. These requirements are antagonistic, because a roll made simply for strength under heat would not have the requisite hardness or depth of chill; its composition probably would not include much, if any, phosphorus, which gives fluidity, and thus prevent a clear surface being obtained; sulphur would not be allowed because it makes iron hot-short, but with it would go the hardness; manganese cannot be substituted, as the face would be so hard that it would shell off. Cast iron to have its maximum strength must contain about two per cent. of silicon, but iron containing this quantity of silicon will not chill to any appreciable extent unless the sulphur is far above the amount that can be allowed in a chilled roll. The question of carbon is so complicated that the author does not venture to give an opinion on it. A good chilled roll is a casting which contains component parts well balanced, that is, the properties of each constituent are up

* *Eisen-Zeitung*, 1898, p. 770.

† *The Celestial Empire*, November 21, through the *American Manufacturer*, vol. lxiv. p. 125; *Iron Trade Review*, February 9, 1899, p. 16.

‡ Paper read before the South Staffordshire Institute of Iron and Steel Works Managers.

to a certain point neutralised by that of another one. For the purpose of making chilled rolls, what is known as a close No. 5 cold-blast Staffordshire pig iron is the nearest approach to an ideal pig iron for the purpose. Other cold-blast brands of Wales and Yorkshire are almost as good, but the price is higher.

The average analysis of a good No. 5 Staffordshire cold-blast pig is as follows :—

| | |
|----------------------------|-------|
| Silicon | 1.110 |
| Sulphur | 0.109 |
| Phosphorus | 0.475 |
| Manganese | 0.646 |
| Graphitic carbon | 2.443 |
| Combined carbon | 0.538 |

It is suggested that the silicon be kept down to 1 per cent., and the sulphur should not be over 0.08 per cent. The following analysis shows the effect of adding ferromanganese in the attempt to manufacture some very hard rolls :—

| | Before. | | After. |
|---------------------------|---------|----------------|--------|
| Silicon | 0.900 | | 0.950 |
| Sulphur | 0.120 | | 0.080 |
| Phosphorus | 0.520 | Chill 1½ inch. | 0.470 |
| Manganese | 0.420 | | 0.560 |
| Graphite | 0.540 | | 0.900 |
| Combined carbon | 3.360 | | 2.930 |

The chill before the addition was 1½ inch with a close hard back, and after it was only ¾ inch with a grey kind of back.

Generally, roll-users ask for a certain depth of chill. Some will say ½ inch to ⅝ inch, others ¾ inch to ⅞ inch for exactly the same kind of work ; some like what is commonly called a painted or clearly defined chill ; others, again, prefer the chill to mingle well with the back. In some cases the purchasers do not mind a little mottle ; such rolls sent to another works would be at once rejected. Although depth of chill is, up to a certain point, a guide, it is far from being a safe one in all cases. Two rolls of exactly the same composition may have different depths of chill ; and, again, two rolls having the same depth of chill may differ very much in analysis.

Cold rolls do not break so suddenly or apparently in such mysterious ways as hot rolls do, and this is ascribed to expansion due to heat. When making large-grain rolls it is customary to melt down old chilled rolls. A few minutes after these are charged into a hot furnace they invariably fly in pieces. Commonly the rupture is transverse,

but it is not at all unusual for them to split up in a longitudinal direction, two or more pieces instead of one. Rolls break at most unaccountable times, not always at the actual time the strain responsible for the disaster has been put upon them, but, as most roll-makers and users will agree, the time the majority of chilled rolls break is at three periods—when they are got up for work on Monday morning, when they are let down at the end of the week, and at night-time. No reason can be ascribed for night-time breakage, but the enormous strain set up from too rapid gain or loss of heat will account for fractures at the other times. Boilers are frequently damped down from Saturday to Monday; regenerative furnaces, &c., are kept going to save a little fuel. Why cannot rolls be kept warm, and thus frequently save a valuable tool?

Rolls are often said to have their necks twisted off, and this form of fracture is ascribed to the strains set up between the body and the neck by variations of temperature. It is difficult to keep the neck at the right heat, but it should be done. Larger bearings and housings are also advised.

Some rolls break because they are used too soon after their being cast: they are pulled out of the moulds too soon, and put to work too soon, though they improve by standing. Rolls also break because the mills are too small for their work, or because the rolls are badly built, or are in a bad state of repair, or are not properly turned. The harder work they now have to undergo is also accountable for many failures, and it is almost impossible to keep the rolls properly cool under stress of work.

Fine Artistic Castings.—Persifor Frazer* gives an illustration of a cast-iron medal with the sprue attached, which was presented to the members of the Geological Congress at Kytchym. The detail of the design is very sharp and clear. On analysis the metal showed:—

| Iron. | Manganese. | Common Carbon. | Graphite. | Phosphorus. | Silicon. |
|--------|------------|-------------------|-----------|-------------|----------|
| 94.063 | 0.425 | 1.644 | 2.530 | 0.642 | 0.562 |

Analyses are also given of the ores and limestone, and of the pig iron from which the medal was cast.

R. W. Raymond† adds that a very interesting illustration of

* *Transactions of the American Institute of Mining Engineers*, October 1898 (advance proof).

† *Ibid.*

delicate castings in low relief was furnished in 1887 by the remarkable reproductions in cast iron of carbonised lace, &c., for which A. E. Outerbridge received from the Franklin Institute a medal. The novelty consisted in the method by which lace, leaves, and other organic fabrics or structures were previously carbonised before introduction into the moulding-flask. The objects were placed in a cast-iron box and embedded in powdered carbon. The box, covered with a close-fitting lid, was heated gradually in an oven to expel moisture, and the temperature was slowly raised until the escape of blue smoke from under the lid had ceased. The box was then heated to a white heat for two hours, and subsequently cooled. The fabrics, &c., thus carbonised were not brittle, and could be made white-hot before consuming. In making castings from them they were laid smoothly upon a face of green sand in the mould, and the molten metal was poured upon them. In one case a piece of lace was suspended vertically in the mould, and the molten iron was introduced on both sides of it, so as to rise to a common level. When the casting was cold it was thrown upon the floor of the foundry, and separated into two parts, while the lace fell out uninjured, and the pattern was found to be reproduced upon both faces of the casting.

The manufacture of ornamental iron is considered by C. B. Albee.* Early forms are first referred to, and then the methods of modern manufacture are described.

Cast Iron.—R. Moldenke † generally reviews the subject of cast iron, its manufacture, uses, methods of treatment, chemical and physical properties, &c.

M. M'Dowell ‡ discusses the effect of silicon and other elements on the value of cast iron, and refers to the methods of grading by analysis and by fracture.

T. D. West § gives an illustrated account of the method of casting test-bars for the testing committee of the American Foundrymen's Association. The bars, &c., are all cast vertically in green and in dry sand moulds from common runners, and great care is taken in the design and preparation of the moulds.

* *Proceedings of the Engineers' Society of Western Pennsylvania*, vol. xv. pp. 150-173.

† *Ibid.*, vol. xiv. pp. 240-265.

‡ *Journal of the American Foundrymen's Association*, vol. v. pp. 316-326.

§ *Ibid.*, pp. 301-315.

Malleable Castings.—G. C. Davis * gives an account of the early history of malleable cast iron in the United States. In that country the first malleable castings were made at Newark, New Jersey, by Seth Boyden, and a sketch of his extensive experiments is given by the author, and also a description of the plant used and articles produced. Boyden's connection with the business terminated in 1835, but several of his brothers later on started other foundries, and the manufacture rapidly extended. The other early works are mentioned.

Further notes by the same author † have also appeared, and relate chiefly to a method of annealing by passing water-gas over the red-hot castings. This method, known as the Andrews process, did not meet with success. At the present time there are about ninety works making malleable castings in the United States, and their capacity ranges from 1 to 80 tons daily.

E. C. Wheeler ‡ deals at considerable length with the influence of silicon, sulphur, carbon, phosphorus, and manganese on malleable cast iron.

Gun Iron and Semi-Steel.—According to T. Ulke, § in the manufacture of gun and mortar carriages in the United States, gun iron, designated as cast iron No. 2, or its accepted equivalent, semi-steel, is largely used. The material is specified to be charcoal iron with an elongation of 0.25 per cent. before rupture, and a tensile strength between 28,000 and 39,000 lbs. per square inch. Strong castings, fulfilling the requirements, can be produced by remelting grey pig (to which scrap steel is sometimes added) in cupolas or air-furnaces in three principal ways, as follows, the percentages being given as examples :—

| | Air Furnaces. | Cupolas. | Cupolas. |
|-------------------------------|---------------|----------|----------|
| Charcoal iron | 35 | 40 to 80 | ... |
| Charcoal iron scrap | 40 | ... | ... |
| Coke iron | 25 | 20 | 60 |
| Gun iron scrap | ... | 20 to 30 | ... |
| Steel scrap | ... | 10 | 40 |

* *Journal of the American Foundrymen's Association*, vol. v. pp. 263-280.

† *Ibid.*, February 1899; *Iron Age*, February 9, 1899, pp. 14-16.

‡ *Iron Age*, February 16, 1899, pp. 2-5; February 23, pp. 4-6.

§ *Iron Trade Review*, December 1, 1898, pp. 8-10.

The various kinds of material used are specified in greater detail by the author, and other particulars are given, including the following typical analyses:—

| | Si. | P. | S. | Mn. | Graphite. | Combined Carbon. |
|------|------------|------|------|------|-----------|------------------|
| | 0.94 | 0.44 | 0.05 | 0.31 | 2.40 | 0.63 |
| II. | 0.8 to 1.2 | 0.30 | 0.05 | 0.60 | 1.40 | 1.0 to 1.2 |
| | 1.53 | 0.29 | 0.05 | 0.45 | 3.01 | 0.42 |
| | 1.34 | 0.08 | 0.03 | 1.00 | 2.19 | 0.93 |
| III. | 0.98 | 0.43 | 0.06 | 0.43 | 0.96 | 0.75 |

The methods of taking and treating test-pieces are also discussed.

Semi-Steel.—The following analyses of semi-steel have been published : *—

| | | | | | | | | |
|----------------------------|-------|-------|-------|-------|-------|-------|-------|-------|
| Silicon | 4.07 | 4.04 | 4.11 | 3.79 | 1.74 | 2.491 | 2.373 | 2.243 |
| Sulphur | 0.091 | 0.107 | 0.078 | 0.117 | 0.099 | 0.088 | 0.095 | 0.100 |
| Phosphorus | 0.95 | 0.783 | 0.925 | 0.861 | 0.434 | 0.839 | 0.771 | 0.706 |
| Manganese | 0.58 | 0.36 | 0.39 | 0.35 | 0.684 | 0.717 | 0.499 | 0.790 |
| Graphitic carbon | 1.83 | 1.75 | 1.72 | 1.73 | 1.42 | 2.620 | 2.530 | 2.383 |
| Combined carbon | 0.11 | 0.13 | 0.03 | 0.08 | 1.56 | 0.556 | 0.666 | 0.785 |

* Of these, the first four are of metals made by B. S. Summers and R. J. Barr, and the others are by various makers. It will be noted that the carbon is low in quantity as compared with the usual run of cast iron, and is chiefly in the graphitic state. Silicon is high as a rule, but the percentages of this and the other elements vary largely.

Moulding.—Illustrations have appeared † of Pridmore's machine for moulding steam-pumps, and other large articles.

R. H. Palmer ‡ describes the manufacture of light cores for foundry work by girls in place of men or boys in several American foundries. The work is done satisfactorily.

* *Iron Trade Review*, November 3, 1898, pp. 8-9.

† *Iron Age*, March 23, 1899, p. 1.

‡ *Iron Trade Review*, November 3, 1898, pp. 16-17.

Amongst the moulding machines recently illustrated are those designed by L. Poole * and by A. F. Cothias.†

E. O. Sachs,‡ in the course of a series of articles on fire protection in Europe, refers to ironworks, especially to the pattern-shop and to other foundry buildings.

The moulding of wheels is described by Spalding.§

* *Iron Trade Review*, January 5, 1899, p. 14.

† *Revue Industrielle*, 1899, pp. 155-156.

‡ *Engineering*, vol. lxxvii. p. 66.

§ *American Machinist*, 1899, pp. 208-210.

PRODUCTION OF MALLEABLE IRON.

Puddling.—Hubert Bya * observes that the operation of puddling ought to be so much the longer, as it is desired to obtain the puddled bars of a higher quality, *i.e.*, free from carbon, silicon, and phosphorus, and it is this which increases the furnace loss, as also the coal consumption. He also remarks, incidentally, that stepped grates only give good results with forced draught, when a preliminary distillation of the fuel is effected, for utilising all the air introduced, the quantity of which may easily be regulated. The useful sectional area of the rectangular grate in a puddling furnace with two working doors that he brought to the notice of the members, is 5 square feet, the area of the hearth 32 square feet, and the capacity of the laboratory or hearth 65 cubic feet. The quantity of coal burnt in twelve hours is 2·3 tons. The coal generally used is a mixture of slack containing 15 per cent. of ash, and at the outside 30 per cent. of volatile matter, with slack containing from 14 to 18 per cent. of volatile constituents, and 10 to 15 per cent. of ash. The waste heat is utilised for firing the boilers. Of the heat generated, part is used for melting the pig iron, and part for vaporising the water in the boilers; and while part remains in the gases escaping up the chimney, another part is lost through conduction and radiation. The 2·3 tons of coal develop 14,662,500 calories, and leave 460 lbs. of ash. During twelve hours 11 cwt. of ash is formed.

Catalan Forges in Brazil.—The *Brazilian Bulletin* contains an account of the Ypanema Iron Works, San Paulo, Brazil, which date from 1590, in which year two Catalan forges were set up. These Catalan forges were certainly built prior to any ironworks in the United States or Canada.†

* *Revue Universelle des Mines*, vol. xliii. pp. 238-256.

† *Engineering and Mining Journal*, vol. lxvii. p. 201.

Native Iron Manufacture.—J. M. Nisbet * gives a short account of the native iron manufacture in Angola, and describes how he utilised the natives to repair a 3½-inch shaft by welding on one and two ounce nuggets of iron. After four days' work the shaft was made long enough, though of no particular shape, but when turned it showed no flaw.

The only reference to iron made by H. Cayley-Webster † in his account of his voyages through New Guinea and the neighbouring islands is a brief mention and illustration of a native forge in the Kei Islands. The bellows consist of two bamboo cylinders three feet high, with bunches of feathers on sticks to constitute the pistons.

Iron in Ethiopia.—At present the needs of Ethiopia as regards iron are met by its own home industry, the seat of which is at Finfani, which is situate at about the centre of the country. Clay furnaces of chimney-like form are built up, and of a capacity of about nine or eleven gallons. These are filled with a mixture of small pieces of charcoal and ore previously mixed together. The furnace is then closed with an iron plate covered with clay, and fire having been previously kindled, it is blown up by four skin bellows. A spongy mass results, which is removed from the oven, cooled down, again broken up into bits, and again charged into the furnace. The process is then practically repeated, except that the bellows are now put above instead of below. On withdrawing the reduced metal, it is broken down on flat stones, first with light and then with heavy hammers, the slag being driven out in this way, and an iron produced that is stated to be of excellent quality. The metal is then brought to a flat shape, the piece weighing some 18 or 20 lbs. The consumption of fuel is naturally large. The ore is found in the neighbourhood, and is quarried in a very primitive way.‡

* *Cassier's Magazine*, vol. xv. pp. 433-435.

† "Through New Guinea and the Cannibal Countries," p. 182. London: T. Fisher Unwin. 1898.

‡ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xli. p. 684.

FORGE AND MILL MACHINERY.

Forging Presses for Armour.—In a series of articles on the production and supply of armour for naval purposes, attention is directed to the plant and processes employed, and a number of illustrations are given * of forging presses. These include a 2000-ton Davy forging press (two drawings); a Whitworth 5000-ton forging press; the Whitworth 3000-ton forging presses at Essen and Bethlehem; the 12,000-ton Whitworth press at the Homestead Works of the Carnegie Steel Company; the 3000-ton bending press at Homestead; the 3000-ton forging press at the River Don Works, Sheffield; and the fluid compression plant at Bethlehem. A list given of the leading forging presses at armour-plate works at home and abroad shows eight in this country, five in the United States, three in Germany, four in France, and one each in Austria and Russia, with powers ranging from 3000 to 14,000 tons. Some particulars of these presses are also given.

The History of the Rolling-Mill.—W. F. Durfee † gives several illustrations and descriptions reproduced from old writers, such as De Caus, Branca, Zonca, Swedenborg, and Polhem, to show the evolution of the rolling-mill.

Improvements in Rolling-Mills.—Lantz ‡ states that if a comparison is made between the quantities produced annually of rolling-mill products made of weld iron and of ingot metal, it will be found that up to about 1880 the former was by far the larger. From that date the use of ingot metal made rapid progress, and in eleven or twelve years it exceeded the weld iron in quantity employed, while in 1896 it was in Germany nearly $3\frac{1}{2}$ times as much.

* *Iron and Coal Trades Review*, vol. lviii. pp. 195-197.

† *Cassier's Magazine*, vol. xv. pp. 478-486.

‡ *Stahl und Eisen*, vol. xviii. pp. 979-1000; twelve illustrations.

The author proceeds to compare the rolling-mills in use in 1870 with those now erected. Some of the former are still at work, and it will be seen that in those days an effort was made to confine the rolling-mill plant within the smallest possible area. The heating furnaces were placed close to the rolling-mill, as well as the shears or saw. Mechanical auxiliary appliances were scarcely used, and the possibility of being able to roll considerable lengths was scarcely taken into consideration. Nowadays, the endeavour is to keep the rolling-mill space as clear as possible. The furnaces, it is true, are still put near to the breaking-down mill, but they are placed at one side, leaving the mill free. Shears and saws are placed at considerable distances away from the rolls, and where great lengths are rolled two or more shears and saws are placed in a line with a good distance between them. Mechanical appliances also largely replace the manual labour formerly necessary. Weld iron and ingot metal require different treatment when being rolled. The former must be at a good even rolling heat, and must be brought to the rolls as rapidly as possible from the furnace and rolled as hot as can be arranged for. It is only necessary to avoid the bar passing through the last two passes at such a temperature that it gets a rough surface and does not quite fill the final pass in the roll. Sometimes it is necessary to use a steam-hammer before passing the metal through the rolls, or to break it down by a preliminary rolling. In the case of ingot metal this must not be brought in the furnace to a full welding heat if danger of spoiling the metal is to be avoided. On the other hand, there need not be much fear, even if the temperature should sink below the normal, if the rolls are but strong enough and the passes cause no difficulty. Ingot metal can be rolled of any desired length, but it is not possible to arrange for this readily in the case of weld iron. In the case of ingot metal, too, there is a practical limit, as the steelworks cannot cast faultless ingots above a certain length in regular practice on a large scale. It follows that for weld iron less powerful rolls and engines are needed than are required for ingot metal, in view of the fact that at the higher temperature at which it is rolled, the weld iron is softer and more easily dealt with than is the ingot metal. On the other hand, ingot metal can be rolled in much greater lengths, and the end temperature is not a cause of so much anxiety as in the case of the weld iron.

After this general review of the position the author proceeds to consider the various portions of a rolling-mill in detail. In the first place,

the furnaces required for the purpose of reheating the material to be rolled are dealt with. Formerly, furnaces with direct firing were solely employed, and, as a rule, these are still in use in weld iron works, either natural or forced draught being employed. This forced draught is produced either by the use of a fan or of a steam jet. If the latter is employed, care must be taken that the steam used is as dry as possible. The latter is usually preferred to fans, being cheaper to erect, easy to manage, and probably not so expensive to keep at work. Generally speaking, the hearths of these furnaces are not much longer than they are broad, to ensure the temperature being adequately high at all parts of the hearth. To get rid readily of the slag that forms in considerable quantities, the hearths are slightly inclined towards the stack end, where the slag can be allowed to flow constantly through a tap-hole, a small coal fire being kept at this point to prevent the slag solidifying. The author, considering the question of furnaces of larger size, refers to the introduction of gas-firing. By this kind of firing much higher temperatures are obtainable than is possible with direct firing. The author describes and illustrates a gas-fired furnace provided with regenerator chambers. Gjers' soaking-pits are next dealt with, and the Pietzka revolving furnace is also considered. This is worked like an ordinary open-hearth furnace, except that instead of the direction of the gas being changed, the furnace hearth itself is lifted, rotated through 180°, and is then lowered again. The author considers that the Laughlin-Reuleaux continuous heating furnace is probably the most recent innovation of this kind. The hearth of this furnace slopes up at a considerable angle from the fireplace. The hearth is then quite filled by continuous charging from the back by the aid of a hydraulic ram. Fresh metal is charged in at the back, so the heated material is forced out at the front, and is taken on driven rollers to the rolls. Such a furnace is stated to have a capacity of some 75 to 100 tons per shift. This furnace the author illustrates and then proceeds to a consideration of the arrangements which have from time to time been employed, or proposed to be employed, for charging the metal into the heating furnaces and subsequently withdrawing it. Of late, he observes, in a few instances, electricity has been made use of as the motive power for such appliances. The next point considered is the transfer of the heated material to the rolling-mills. This is effected in a variety of ways. The engines employed are next dealt with, and the rolling-mills themselves considered in some detail, together with the mechanical devices that have been introduced for the purpose of

facilitating their manipulation. The author also deals with the question as to whether it is more advantageous to employ a 3-high or a reversing mill. He does not consider it possible to answer this question directly. Up to now 3-high mills have only been erected for the purpose of dealing with fairly light material, the maximum limit of their efficiency being placed at the production of beams some $15\frac{1}{2}$ inches high, while reversing mills are used for heavier work. Each kind of mill has its own particular advantages as compared with the other, and whether one kind of mill or the other is to be erected must depend on a variety of questions, such as the space available, cost of steam-power, wages, &c. Rolling-mills for ingots are specially dealt with, and the author refers to the question as to the size of the ingots that should be cast. This must, he thinks, depend on circumstances. A discussion ensued on the reading of the paper.

M. Meier,* discusses the production of rails, sleepers, and beams. In the first place, the author refers to the preliminary treatment of the ingot in the rolling-mill, describing this and the shears and other appliances employed. He then proceeds to a consideration of modern methods for the manufacture of sheets, rails, and other products, giving illustrations of various mills, chiefly from United States practice, the plant of the Edgar Thomson Works of the Carnegie Company, and that of the South Chicago works of the Illinois Company being specially referred to. The use of electro-motors for driven rollers is discussed, and the continuous rolling-mill of the Morgan Constructing Company, Worcester, United States, is also mentioned, as also is the beam-mill of H. Grey, which the author considers to possess considerable advantages. A discussion ensued on the reading of the paper.

A. Sattmann† considers various improvements in rolling-mills. Dealing first with gas-fired soaking-pits, he refers to the difficulty that is experienced with these in keeping the bed at exactly the desired height, a difficulty which at some works has led to their rejection. The author describes and illustrates an arrangement he adopted to meet this difficulty. It is of a more complicated character than an ordinary soaking-pit, but gives excellent results. The loss of metal when the ingots were charged in hot is from 1 to 2 per cent., and from 2 to 2.5 per cent. when cold ingots are charged in. The furnace lasts very well. About every six weeks the roof must be repaired,

* *Stahl und Eisen*, vol. xviii. pp. 1017-1036; fourteen illustrations.

† *Ibid.*, vol. xix. pp. 72-75; three illustrations.

and once every twelve or eighteen months a general overhaul is necessary, the repairs then requiring about a fortnight to complete. No difficulty with the slag is experienced, this flowing away regularly. The author then discusses rolling-mills, and especially three-high plants. He points out that modern three-high plants driven by reversing-engines possess one important advantage over other similar mills not so driven which is apt to be overlooked. They can be brought to rest at once should this be necessary.

Continuous Rolling-Mills.—In an editorial article *Stahl und Eisen* * discusses the question of continuous rolling-mills. As far back as 1842, it is pointed out, J. E. Serrell took out a patent for such an appliance, although apparently one was never erected. Here the rolls were placed first horizontal then vertical, then again horizontal, and so on. It was not until twenty years later that G. Bedson, of Manchester, brought the continuous rolling process to actual practical success. In 1869 the process was introduced into the United States. The Bedson mill also possessed vertical as well as horizontal rolls, and the first mill of this kind with only horizontal rolls was not erected until 1879. The progress that has been made since that time is referred to, and illustrations are shown of the Morgan plant at Worcester, Massachusetts.

The Sack Universal Rolling-Mill.—H. Sack † describes and illustrates his universal girder rolling-mill. He points out various advantages he considers it to possess.

Application of Driven Rollers.—G. von Bechen ‡ describes and illustrates a three-high rolling-mill provided with driven rollers, and so arranged that all ordinary lifting is practically done away with. The ingot having been passed between the two lower rolls, comes on to a roller-table placed behind the rolls and worked by steam or hydraulic power. This lifts the ingot and passes it back between the two upper rolls. The ingot is not then caught by the rolls, but falls direct on to the rollers. In the second stand of rolls the lifting table is done away with, the bar being then usually long enough to admit of being otherwise handled. For very heavy ingots falling cannot of course be allowed, but this works all right for ingots up to a ton in weight. In

* Vol. xix. pp. 16-18; three illustrations.

† *Stahl und Eisen*, vol. xviii. pp. 1076-1078, with a sheet of illustrations.

‡ *Ibid.*, vol. xviii. pp. 934-935, with two illustrations.

the mill the author refers to, the output in twenty-four hours is from 600 to 700 tons with two or three stands of rolls, according to the nature of the product.

A New Sheet and Bar Mill.—At the Shenango Valley Works, Newcastle, Pennsylvania, a new sheet, bar, and billet mill has been erected for continuous work. There are twelve trains of rolls, one behind the other at distances varying from 34 to 54 feet apart, and covering a total length of 406 feet. The first eleven trains have two stands each, one for bars and the other for billets. The blooms are cut up in suitable lengths, which are passed successively through all the stands, or in the case of light work the bar is cut into two at the sixth roll, and the two halves go on side by side. The trains are driven by four engines in groups of three by rope-gearing arranged to give the proper speeds. Each table is driven by a separate electromotor. A plan of the arrangement is given.*

Weighing Machinery in Rolling-Mills.—Illustrations have appeared † of a design for a weighing machine used in connection with a slabbing-mill, the scale itself being similar to an ordinary weigh-bridge pattern. It is built into a hydraulic manipulator. The slabs pass along on the rollers above the scales, and when the weight is desired the manipulator is worked by hydraulic power until the lifters pick up the slab, so that it then rests upon the scale, when the weight can be quickly ascertained without stopping the roll train. It is enclosed as much as possible, so as to be thoroughly protected against heat, scales, and cinder.

Rolling-Mill Tables.—F. I. Freeman ‡ uses an electro-magnet to divert a defective sheet or other work from the main live rollers of a mill table on to an apron and second set of rollers. Illustrations are appended.

The Design of Roughing Rolls.—W. Hirst§ discusses the design of roughing rolls. Short mention is first made of the improved mixtures used for casting rolls, and the consequent reduction in their size,

* *Iron Trade Review*, March 9, 1899, pp. 11-13.

† *American Machinist*, vol. xxi. pp. 790-791.

‡ *Iron Trade Review*, February 9, 1899, p. 8.

§ *Iron Age*, March 16, 1899, pp. 2-5.

and then of the advantages of roughing passes which bring the ingot approximately to the form of the finished section. The work that the roughing mill has to do is not confined to reducing the area of the ingot, but it also has to give the metal a fibrous structure, and in the case of piles to weld the component parts together into a solid mass. Excepting the rod trains, there are three general forms of passes used in merchant trains—the diamond, gothic, and the box pass. The gothic pass is the diamond form with concave sides, and both of these act on the opposite corners, while the box-pass acts on opposite sides of the work. Practice has proved that angles of 100° and of 80° give the best results in the angular passes, and a fair reduction is from 126.5 to 100 in area, or about $1\frac{1}{8}$ inch to 1 inch. The extremes are about 130 and 120 to 100. Above this fins are formed, and below the bar does not properly fill the pass. In these forms of passes the reduction depends on the constant changing of the angles of the bar, and this is pernicious in the case of piled bars, as it tends to open cracks instead of welding them. On the other hand, it is of advantage when rolling puddled balls, as it aids in squeezing out the cinder. The box-pass is more efficient for welding, and its reducing power is greater, especially for larger sizes. The box-pass is flat, square, or edging, the latter being used when flat bars are turned on edge. Various designs of these forms are illustrated and discussed, and they are considered the best for work down to 2 inches square.

Armour-Plate Mills.—A number of illustrations are given * of the rolling-mills used for making armour. These include the mills at the Don Works, Sheffield, the Homestead Works, the Creusot Works, the Tudhoe Works, the Wishaw Works, and the Bethlehem Works. Some plans and elevations of the Creusot and Bethlehem Works are also given, and the description appended contains many of the leading dimensions.

The Brown Crane.—A. Sahlin † observes that the question of the rapid and economic transport of heavy materials in steelworks is becoming constantly of more and more importance. Ordinary travelling cranes do not as a rule fulfil these requirements adequately, and the author sums up under six separate headings the exact character of the various requirements which a satisfactory crane should possess. These

* *Iron and Coal Trades Review*, vol. lviii. pp. 239-241.

† *Stahl und Eisen*, vol. xviii. pp. 1085-1086 ; three illustrations.

are in brief as follows: (1) The crane must lift freely and travel quickly; (2) its dead weight must be relatively small; (3) it must carry quickly and cheaply from one place to another, no matter how long the space may be; (4) it must cover all the working places required without any excessive increase in the weight of the apparatus; (5) it must take up as little space as possible; and (6) it must always carry girders, rails, shapes, or bridge material in a horizontal position and without these swinging. All these various requirements he considers are fulfilled by the Brown crane, one of which is being constructed for the Rothe Erde Works.

The Ashland Steel Company's Works.—A plan has been published * of the wire-rod mill works at Ashland, Kentucky, which has been recently remodelled to roll wire-rod instead of slabs for making nails. The steel is made in two 5½-ton converters, and the wire-rod mill is of the continuous type for treating 4-inch billets.

* *Iron Age*, February 9, 1899, p. 16, with plate.

PRODUCTION OF STEEL.

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I.—THE CARBURISATION OF MALLEABLE IRON.

Crucible Steel.—C. Caspar * refers to the pouring of open-hearth steel into crucibles and then allowing these crucibles to stand for about an hour in an ordinary crucible furnace properly heated, and queries whether such steel can subsequently be considered and sold as crucible steel. He considers that this is not accurate. True crucible steel is made from selected materials in a special way, and this makes the process a much dearer one, owing to the care given to the various details and the time consumed. The crucibles must be at least three times as long in the furnace in their true process as is required in the case of the one first mentioned. The author thinks it would be possible to obtain satisfactory metal at a much cheaper cost in the following way :—A basic-lined converter or open-hearth is worked in combination with an acid-lined open-hearth in such a way that the finished basic metal is simply tapped into the latter free from any of the slag, which is kept back. The acid furnace is at its highest temperature, and contains a small and accurately known quantity of very pure pig iron. An intimate mixture and carburisation must result, and if the bath be allowed to remain for some forty minutes at its highest temperature, good sound metal must result, he considers. The acid open-hearth should be relatively very deep, short, and narrow, :

* *Stahl und Eisen*, vol. xix. pp. 277-278.

the air and gas openings arranged so as to give the highest possible temperature.

A French translation has been published of the important researches on cementation carried out by F. Mannesman * in 1879.

II.—THE OPEN-HEARTH.

Mechanical Charging of Steel Furnaces. — H. Tomkins † describes a machine invented by himself, and introduced at the Moor Steel and Iron Works, Stockton-on-Tees, where, after twelve months' trial, eight machines have been put up—one to each furnace. The machine consists of a hollow shaft or shoot, with an elevator or overhead railway for feeding the material directly into the shoot, through which it passes by gravity into the furnace. In its simplest form the shoot is mounted on two girders. These are fixed upon an overhead travelling crane arrangement, which enables it to be carried along from one charging door to another, as required. The shoot may also be mounted on trunnions, so that it can be drawn back out of the way when passing furnace doors, or be projected into the furnace door as required. The crane path is so arranged that the shoot can be travelled from furnace to furnace where the furnaces are in line. The shoot is built up of steel plates, a double thickness of plates being used, so that the inner plate can be changed when worn out, the outer plate forming the framework and keeping the shoot in its proper shape. Experience has shown that a layer of asbestos between the plates composing the shoot deadens the noise made by the falling materials, and also helps to keep the shoot cool. The details of the shoots and of the elevators for feeding the shoots are described. The material is taken by the elevators from an inclined loading-table, alongside which the railway trucks run to be discharged by hand.

It has been found by experience that the damage to the lining of the furnace is inconsiderable in spite of the shock of the falling material as long as the machine is properly designed.

One objection urged against charging by machinery was that the pig iron could not be placed around the furnace. That has proved to be of no consequence, the experience at the Moor Works being that it does

* *Bulletin de la Société d'Encouragement*, vol. iv. pp. 473-477.

† Paper read before the Cleveland Institution of Engineers, April 24, 1899.

not make the slightest difference whether the pig iron is piled carefully around the furnace banks, or thrown by the machine all over the bottom and piled up against the back wall. In charging, the pig iron is first put in, and while it is going in at one door the furnaceman places about half-a-dozen half-pigs just inside the other doors. The machine is then moved on to the next door, and the furnaceman places the pig on the inside of the door the machine has just been removed from. The machine is moved to the next door. Three truck loads having gone in, *i.e.*, one truck to each door, the pig iron now covers the whole of the bottom of the furnace. The scrap is next fed into the machine until there is half a truck load thrown into the end door. The machine is then run back to the other end door, and the remainder of the truck of scrap goes in there. The machine is then taken to the middle doors and a whole truck of scrap thrown in; and last of all a truck of pig iron is distributed among the three doors, so that practically the scrap is in the centre of the furnace. The operation of charging is now complete, and the time occupied in charging 45 tons of pig iron and scrap by five men has been checked at 45 minutes. The saving in labour and other matters are also discussed.

The Basic Open-Hearth Process in Westphalia. — K. Johansson * observes that German furnaces can obtain large quantities of scrap, so much indeed that the acid furnaces work with 90 per cent. of it, and the basic furnaces with 85. The arrangements of the furnaces are generally well adapted for large out-turns. They are usually similar in form, and it is only at the Phoenix Works that two new 20-ton furnaces of the Riley form with round producers are met with. The dimensions of the furnaces vary with the size of the charge to be dealt with. These vary between 5 and 25 tons, the most suitable being considered to be from 15 to 18 tons. Various furnace dimensions are given, and the mode of construction described. The producers are fed either with bituminous coal or with brown coal, the latter also yielding a satisfactory gas. Körting injectors are used to force air into the producers below the firebars, and fans are also made use of. In Hörde at the steel-foundry three producers are always at work, and one in reserve, the open-hearth plant there possessing sixteen producers placed in four rows of four producers each, but only twelve of these are used daily. The three 20-ton furnaces at Hüsche have six step-grate producers 13 feet in height and 5 feet in diameter. Four of

* *Jernkontorets Annaler*, vol. liii. pp. 208-256.

these supply the gas for these three large furnaces. Water-gas does not appear to be used anywhere in Westphalia, although at Hörde it was much praised, apart from its very explosive character.

The acid bottoms are always sintered together, Rhine sand being used with some basic material, the mixture being so arranged that it shall sinter well together, but not actually melt even at the highest temperature in the furnace. The method of procedure in connection with the stamping-in of basic hearths is described, powdered chrome iron ore being used as a parting between the acid and basic materials. The method employed in getting the furnace into actual work is also dealt with in detail.

Dealing next with the furnace charges, the author points out that the boil is a very short one, owing to the large quantities of scrap used. He gives the constituents of a series of charges. In all furnaces the carbon is eliminated as far as possible, the desired degree of hardness being subsequently given to the metal by the addition of spiegeleisen, ferro-manganese, and ferro-silicon. The author only saw the recarburisation effected by powdered coke in the case of basic open-hearth steel at Hösch and at the Phoenix Works. At basic Bessemer works, however, where rail steel is being made, powdered coke is universally employed for this purpose to save the more expensive spiegeleisen. At each open-hearth works the addition is made to the ladle when tapping, the charcoal powder or coke powder being charged in small packages each containing about 2 or 3 lbs. At the Phoenix Works a couple of pounds of the loose powder are also strewn over the ladle before the metal is charged into it. Much secrecy is shown in connection with this, but it is certain that the charcoal or coke powder must be perfectly dry before it is used.

The method of working the open-hearth furnaces is described. Very large percentages of scrap are used, as has been previously stated. After charging, as much gas as possible is passed in to make the melting down as rapid as possible, this being about the most important point in the whole process. For the basic hearth, too, this is a most important matter. If the gas is able to play upon a portion of the uncovered hearth, it softens it considerably, and during the boil such a spot is then always greatly attacked, a hole being produced. If no limestone was added with the charge after it has run down, about 2 per cent. is added, and more is subsequently added if necessary. Very little ore is usually required, so much scrap being used. Spanish hæmatite is the ore generally used. The various recarburising and deoxidising

additions are always strongly pre-heated, either at the working doors or in special furnaces. In the first case a thin layer of lime is first put on the dolomite to prevent adhesion, on this the spiegeleisen is placed, on top of this the ferro-silicon, and on top of all the ferro-manganese. This pre-heating is continued until the ferro-manganese and ferro-silicon begin to melt. They are then all pushed rapidly into the bath, and stirred for about a minute.

The cleaning and repairing of the furnaces is considered in some detail, and the ladles, moulds, &c., in use are also considered. The testing methods in use are also mentioned, those at the Phoenix Works being stated in detail. In connection with this the following table is given :—

| Carbon. | Tensile Strength. | Elongation. | Degree of Hardness. |
|--------------|-----------------------|-------------|---------------------|
| Per Cent. | Tons per Square Inch. | Per Cent. | |
| 0·06 to 0·10 | 21·6 to 24·1 | 25 to 30 | 000 |
| 0·10 to 0·15 | 24·1 to 26·7 | 22 to 25 | 00 |
| 0·15 to 0·22 | 26·7 to 29·8 | 20 to 24 | 0 |
| 0·22 to 0·28 | 29·8 to 32·4 | 20 to 22 | 1 |
| 0·28 to 0·33 | 32·4 to 35·5 | 18 to 20 | 2 |
| 0·33 to 0·38 | 35·5 to 38·7 | 16 to 20 | 3 |
| 0·38 to 0·45 | 38·7 to 43·2 | 15 to 18 | 4 |
| 0·45 to 0·50 | 43·2 to 47·0 | 14 to 16 | 5 |
| 0·50 to 0·55 | 47·0 to 50·8 | 12 to 15 | 6 |
| 0·55 to 0·60 | 50·8 to 54·6 | 10 to 12 | 7 |
| 0·60 to 0·68 | 54·6 to 57·1 | 8 to 10 | 8 |
| 0·68 to 0·75 | 57·1 to 63·5 | 5 to 10 | 9 |

The loss of metal is largely dependent on the percentage of scrap that is used in the charge. If this is large and free from rust, then the loss is usually not more than 4 or 5 per cent. Otherwise it may reach 8 or 9 per cent. Excellent results are also obtained in regard to the fuel consumption. At Hörde, for instance, this amounts to from 30 to 35 per cent. of the weight of metal produced, and at the Gutehoffnung Works to only 25 or 30 per cent. At this last works hot scrap is added, the furnace making six charges a day. It is stated that at the works of the Bochum Company the consumption of fuel has been brought down to about 25 per cent. These results, the author observes, are due to rapid working, with a resulting high out-turn.

Manganese in the Open-Hearth Process.—F. A. Matthewman * discusses the use and action of manganese in the open-hearth acid pro-

* *Journal of the West of Scotland Iron and Steel Institute*, vol. vi. pp. 91-121.

cess. It is contended that manganiferous pig iron within certain limits ought not to be objectionable, while it is admitted that practical difficulties do arise in its use, but possibly they may be ascribed to other causes. In the discussion, the opinions expressed were adversely criticised.

Sulphur in the Open-Hearth Process.—F. Stille * discusses the behaviour of sulphur in the manufacture of ingot metal. He points out that the views as to this which have been published have been very various, and gives the results of some experiments made in a gas-fired open-hearth working on a charge of 80 per cent. pig iron and 20 per cent. scrap, together with some ore. A series of samples were taken at intervals during the working of the charge, and subsequently analysed. The results obtained are given by the author. He shows that during the melting down of the charge the metal does not take up sulphur from the gas, as is usually assumed, but, as a matter of fact, becomes largely desulphurised, at least if this is as low as it was in the case in question—0·015 per cent. The same result, the author observes, would probably happen with higher sulphur metal, and he quotes a case in which a charge with 0·030 of sulphur yielded a final product containing only 0·015 to 0·020 per cent. of sulphur. The analyses having shown that the percentage of sulphur increases as the percentage of carbon begins to diminish considerably, it is probable that at the end of the melting-down stage the percentage of sulphur did not exceed in the above instance 0·010. The sulphur contents diminish during the melting down, then remain fairly constant until the ore addition is made, then sink slowly until the percentage of carbon has reached 0·7 to 1·0 and then rise again, and that the more the percentage of carbon has diminished. If the iron is decarburised as far as possible, it will take up from 0·015 to 0·020 per cent. of sulphur. The causes of these variations lie in the manganese contents of the charge, in the addition of ore and in the sulphur contents of the gas employed. The considerable diminution in the sulphur contents during the melting-down stage is readily explainable on account of the manganese contents of the charge.

American Steelworks.—A plan has been published † of a new steel and iron works now being built at Portsmouth, Ohio. There are

* *Jernkontorcts Annaler*, vol. liii. pp. 393-397.

† *Iron Trade Review*, February 2, 1899, pp. 12-13.

four 35-ton basic open-hearths, two 40-ton acid open-hearths, and two crucible furnaces. Wellman charging-machines and ingot mould trucks are used. Details are also given of the rolling-mill plant, which includes a 72-inch plate-mill and others.

Illustrations have appeared * of the Ohio Steel Works at Cleveland, showing the Wellman charging-machine and the steel-foundry.

The Pietzka Heating Furnaces.—The furnace used at the Witkowitz Works, in Bohemia, designed by Pietzka,† is so arranged that gas is delivered at a temperature of about 900° C. from the producers, which are connected directly with it, the gas being burned directly at the fire-bridge with preheated air. The products of combustion passing over the hearth flow through recuperators, and are used for raising steam. In order to obtain the advantages which Siemens furnaces possess through the reversing of the flow of the hot products of combustion, that part of the furnace which is between the fire-bridge and the flue is supported on a hydraulic cylinder, so that the whole hearth may be raised and lowered. The furnace is worked like a Siemens furnace, with the difference that, instead of reversing the valves at certain intervals, the whole hearth is raised, turned through an arc of 180°, and is then lowered.

The furnace delivers in twelve hours, using 2·7 tons of coal, about 12 tons of iron, the piles weighing 155 to 330 lbs. each, or about 22 tons of steel, from blooms weighing 370 to 490 lbs. each.

The producers are of the Pietzka type, use Ostrau fine coal, and are supplied with Koerting apparatus working with compressed air instead of steam, the pressure being 3 atmospheres. The recuperators are of the Pietzka type.

III.—THE BESSEMER PROCESS.

Metal Mixers.—E. J. Windsor Richards ‡ deals with the advantages of using metal mixers and casting machines, and describes their use at the Homestead Steelworks. The metal is carried a distance of five miles from the Duquesne furnaces in ladles mounted on cars, then poured into the mixer and kept hot by natural gas, repoured

* *Iron Trade Review*, December 15, 1898, pp. 11-13.

† *Stahl und Eisen*, vol. xviii. pp. 979-1000; *Comité des Forges de France*, Bulletin No. 1445, p. 67.

‡ *Journal of the West of Scotland Iron and Steel Institute*, vol. vi. pp. 18-54.

into ladles as required, and charged molten into the Siemens furnaces, the whole operation occupying about one hour. At the same furnaces they tap six or seven ladles of iron of fifteen tons capacity, the ladles being conveyed by rail to Homestead. Coke dust is used to cover the metal in order to retain the heat. The metal is tipped into the mixer by electric power, and when full they run out twenty tons into a ladle, and this is poured into the open-hearth furnaces. Seven to eight hundred tons of metal are thus transported daily. The charge is mixed with scrap and worked in the usual manner. Illustrations of the mixers at Duquesne and at the works of the Cambria Iron Company, and also of the 20-ton ladles are given. After some suggestions for Scottish practice, the author describes the first mixer installed in this country. This was built at Barrow, and passed 7000 tons of Bessemer iron weekly, producing a noticeable saving and reduction of waste.

During a period of eighty-three working shifts, 52,000 tons of molten iron were sent to the mixer, from which 1294 samples were taken, with the results that follow:—Silicon daily average, 2.39 per cent., the highest average for any day being 2.80 per cent., and the lowest 1.95 per cent., variation 0.85 per cent. only. The highest silicon in any one sample was 4.75 per cent., and the lowest 0.82 per cent., a variation of 3.93 per cent. The greatest variation in any day was 3.39 per cent., the highest and lowest on that day being 4.31 per cent. and 0.92 per cent. respectively. During this period 969 samples were taken from the mixer for analysis, giving a daily average of 2.30 per cent. of silicon, the highest 2.75 per cent., and the lowest 1.85 per cent., showing a variation of 0.90 per cent. The greatest variation in any day was 1.75 per cent., the highest on that day being 2.98 per cent., and the lowest 1.23 per cent. The highest silicon in any one sample was 3.29 per cent., and the lowest 1.18 per cent., a variation of 2.11 per cent., the cause of the great variation being the taking out of metal from the mixer faster than it was being put in. Briefly stated, the benefit of passing the metal from the furnaces through the mixer was that the daily average of silicon only varied 0.90 per cent., while from the furnaces it was 3.93 per cent. The mixer that was erected at Barrow, however, was too small—the larger the mixer the less the variation.

The same results may be obtained for the open-hearth process. There is no danger of the metal skulling, as the mixer is entirely closed. In this country the author advises a system of chequer-work,

with gas and air going through the trunnions, as in the Wellman tilting furnace. The object of this is to desiliconise. When the metal cannot be used in the mixer it should be cast into pigs in a casting-machine.

Manufacture of Steel in South Staffordshire.—In a presidential address, H. Le Neve Foster * deals with the prospects of steel manufacture in South Staffordshire. The questions of foreign competition, cheap supply of ores, and their calcination to save the cost of carriage, transport rates, utilisation of by-products and other matters are considered.

The Steelworks of the Charleroi Basin.—J. Smeysters † observes that the smelting works established in the Charleroi Basin have made considerable progress in recent years. The manufacture of steel has made rapid strides, and the rolling-mills in particular have been greatly improved and developed. Two works, those of Couillet and La Providence, each make over 100,000 tons of ingots and 60,000 tons of rolled metal annually, employing the basic process. The La Providence Steelworks, which is situate at Marchienne, is stated by E. Lebacqz ‡ to possess three blast-furnaces of large size, a basic Bessemer plant, rolling-mills, foundries, and shops. The same company possesses plants in France at Hautmont, Rehon, and elsewhere, together with considerable deposits of iron ore. At the Marchienne Works there is produced annually about 102,000 tons of pig iron and 94,000 tons of finished products.

E. Laduron § describes the puddling plant at the Bonehill Works at Hourpes, and J. Smeysters || the Charleroi Steelworks, with its small Bessemer plant, and the Fernand Thiébaud Company's rolling-mills at Marchienne-au-Pont. At the Charleroi Works there are in use small converters of the Cambier type. Illustrations of these are given. They take a charge of from $1\frac{1}{2}$ ton to 2 tons or more. It is blown through three openings at the sides, not through tuyeres properly so called. These openings pass downwards obliquely at an angle of 12° , and are seven in number, so arranged as to induce a rotary movement of the bath. The blast has a pressure of from 400 to 600 millimetres

* South Staffordshire Institute of Iron and Steel Works Managers, January 1899.

† *Annuaire de l'Association des Ingénieurs sortis de l'Ecole de Liège*, vol. xii. pp. 1-10.

‡ *Ibid.*, pp. 32-36.

§ *Ibid.*, pp. 36-42.

|| *Ibid.*, pp. 42-51; three illustrations.

of mercury. The blow lasts from 12 to 15 minutes, and one such converter will last about 160 blows without any important repairs being necessary. Details are given as to this form of converter, which is stated to give satisfaction. The Tropenas type of small converter is in use at the Léonard Giot Works at Marchienne.

The Trignac Steel Works.—Hubert Bya * states that at the Trignac Works, near St. Nazaire, France, there are blast-furnaces, open-hearth and Bessemer plants, rolling-mills, and a foundry and repairing shops. He describes the various portions of this works, paying considerable attention to the rolling-mills. Nearly all kinds of rolling-mill products are made. Bessemer steel is used for the rails made, and open-hearth metal for the sheets, shapes, and other products. The coal used is derived from the United Kingdom, being landed at the port of St. Nazaire. This portion of the works is also provided with a puddling plant. The steel plant is at a considerable distance from the rolling-mills. The Bessemer plant contains two converters. These take 10-ton charges. They are only at work during the day, and make from 19 to 21 blows in the twelve-hour shift. Two large cupolas are used for re-melting the pig iron, and two smaller ones for the spiegeleisen. The open-hearth plant comprises four open-hearths, one of 15 tons capacity, two of 10 tons, and one of 8 tons. These latter are to be converted into 15-ton furnaces. These four furnaces are in constant operation day and night, and take four or five charges in the twenty-four hours. They are basic lined. This plant is provided with thirteen gas-producers, these latter having each a steam jet below the fire-bars. At the date of the author's visit only one of the three blast-furnaces belonging to the company was in blast, but since then a second has been blown in. Each averages about 110 to 120 tons of hæmatite pig iron daily, or from 100 to 110 tons of special rolling-mill metal in the twenty-four hours. The third furnace will make from 125 to 150 tons of pig iron per day. The works also possesses eight batteries of Smet coke-ovens, each battery containing sixteen ovens. The whole works is lit by electric light.

New Russian Steelworks.—A number of new iron and steel works are about to be started in Russia.† One Austrian company

* *Revue Universelle des Mines*, vol. xlii. pp. 311-339.

† *Rigaer Industrie Zeitung*, vol. xxiv. p. 236; *Chemiker Zeitung*, vol. xxiii., *Repertorium*, p. 55.

purposes erecting weld iron and cast steel works in the Charkow and Ekaterinoslaw governments, and an ironworks is to be laid out at Irkutsk by another company.

In the Caucasus new iron ore deposits have been discovered in the Kasach district. The iron industry in the Caucasus is now receiving much attention and several ironworks are proposed.

In the Donetz coalfields the Belgian Coal Company has been authorised to erect ironworks in the Ekaterinoslaw government. Various other new companies are also mentioned.

In the first half of 1898 there were in the Ural district sixty-nine active ironworks, eight of which belonged to the Crown, the other sixty-one being private undertakings. It is estimated that in 1898 these Ural ironworks will produce 43,000,000 poods of pig iron. This represents an increase of 3,000,000 poods as compared with the production in 1897. In the last five years the increase has been as much as 10,000,000 poods. The continued increase in railway construction in the Urals is exerting a very beneficial influence on the iron trade there, existing works increasing their outputs, while new works are also being constructed.

The South Works at Chicago.—An illustrated account has recently appeared * of the blast-furnaces and steel plant at the South Works of the Illinois Steel Company at Chicago. The Bessemer plant started in 1882 has now a capacity of 2200 to 2600 tons of ingots in twenty-four hours. There are three 14-ton converters with concentric noses and removable shells. Iron from the furnaces is charged into two horizontal cylindrical 150-ton mixers, in which the metal may be heated by oil. The charging ladles are tipped automatically on the hoists as they discharge, and the mixers are tilted on their roller paths to draw off the metal. Other details are shortly given, together with a brief account of the rolling-mills and the open-hearth steel plant, in which there are four Wellman rolling-furnaces of 60 tons capacity and two of 25 tons, besides four stationary furnaces of 25 to 30 tons capacity.

The Lorain Steel Company's Works.—R. W. Hunt † gives an illustrated account of the recently built works of the Lorain Steel Company at Lorain, Ohio. The blast-furnace plant was described

* *Engineer*, vol. lxxxvi. pp. 609, 633.

† *Engineering*, vol. lxxvii. p. 3.

at some length in an abstract in the last volume of this Journal.* The illustrations now given include a general plan of the works and of the blast-furnace plant, excavation for engine foundation, the converting department boiler-house, ore mixing and weighing machinery, crane for dumping chill bars, Bessemer converters, power-house, ingot stripping-house, mixing and ladle drying-house, the blooming-mill heating pits, front and rear side of the blooming-mill, rail-mill heating furnaces, rail trains, rail straightening machines, roll-turning and charging rooms. A short description of these is given.

* *Journal of the Iron and Steel Institute*, 1898, No. II. p. 469.

FURTHER TREATMENT OF IRON AND STEEL.

The Weardale Reheating Furnaces.—In some notes on the "Weardale" reheating furnaces at Tudhoe Ironworks, H. W. Hollis * gives some details of the metallic waste in the furnace, which some have supposed to be excessive on account of the powerful oxidising flame employed. A number of steel slabs, both hot from the cogging-mill and cold from stock, were weighed before charging into the furnaces, and again when withdrawn and on their way to the mill. It is obvious that the weight-percentage of metallic waste is in proportion, not to the actual weight of the slabs under treatment, but to their surface area exposed to the action of the flame. As the surface area is in a decreasing ratio to the weight as the weight of the slabs increases, the percentage of weight waste is less for large slabs than for small ones. The mean result shows a loss of 2·45 lbs. per square foot of surface area of the slabs, and this proportion of loss is very nearly the same with cold slabs from stock as with those red-hot from the cogging-mill. This is not an unexpected result, as, speaking broadly, waste does not begin until a certain temperature is attained, and the surface of the slabs begins to "run," and the period and degree of wasting is not affected by the temperature at which the slabs are put into the furnace. The following table gives the mean results :—

| Weight of Slab. Tons. | Superficial Area. Square Feet. | Waste. Lbs. | Loss in Weight. Per Cent. |
|--------------------------|-----------------------------------|----------------|------------------------------|
| 1·5 | 36·3 | 90 | 2·68 |
| 2·0 | 40·9 | 112 | 2·5 |
| 2·5 | 47·7 | 119 | 2·12 |
| 3·0 | 51·4 | 128 | 1·9 |
| 3·5 | 57·2 | 143 | 1·82 |
| 4·0 | 61·9 | 154 | 1·72 |
| 4·5 | 68·2 | 170 | 1·68 |
| 5·0 | 70·0 | 175 | 1·56 |

From 5 to 8 tons the loss remains constant at about 1·5 per cent.

* Communicated by H. W. Hollis.

The character of the flame can readily be modified so that slabs may be held in the furnace. The cost of repairs for the two furnaces during 1898 amounted to about £126 and £32 respectively, but bad bricks were used in the first instance in the roof of one furnace. As the figures stand, they work out to 0·79d. per ton of slabs heated, or less than one-tenth of the cost in coal-fired furnaces. During the year 1898 the furnaces worked $357\frac{1}{2}$ shifts out of a possible 568, or 62·94 per cent. of full time. It is true that part of the time lost was in consequence of a strike; and, applying the necessary correction for this, the time worked amounts to about 68 per cent. of full time. The coal consumed in five producers during the year was 8483 tons, or 23·73 tons per shift, and the weight of slabs heated was 47,939 tons, or 134·1 tons per shift, giving a consumption of 3·53 cwts. of coal per ton of slabs. In full work, this amount is expected to be reduced to 2 cwts., and as it is, the furnaces are working exceedingly well.

Electric Power in Steelworks.—E. B. Clarke* gives some notes on the present condition of electric power transmission in the steelworks of America. Its use for driving charging machines for open-hearths and reheating furnaces, cranes, rolling-mill tables, drills, shears, and punches, and also for exciting magnets used for picking up plates, are described and illustrated. The load diagram for an electric plant in a steelworks is given to show the variation of the power required between 1000 and 214 amperes, with an average of 725 in one case, and between 1500 and 525, with an average of 800 amperes, in a second instance. The nature of the current and the motors used are also discussed, and a pressure of 300 volts is preferred.

Tinplate Manufacture.—A review of the tinplate manufacture since it was introduced into the United States about seven years ago has recently appeared.† The change in the engines, rolls, furnaces, and in the machinery generally is dealt with. Labour-saving arrangements are referred to, and also the effect of heat on the rolls. Donner's arrangements are also described. In this, with five stands of rolls, two of them do the roughing and the others are restricted to the same class of work, either bars, pairs, fours, or eights.

* *Cassier's Magazine*, vol. xv. pp. 441-455.

† *Tin and Terne*, December 1 and 15, 1899.

P. Pasquier * describes the modern methods of tinplate manufacture, and discusses the possibility of its introduction into Belgium.

Welded Chains.—E. J. Taylor † deals with the manufacture of welded chains, and chiefly with that part of the chain trade which includes more particularly the making and testing of the higher classes of welded chains, such as are used for cranes and slinging purposes. After describing the various processes in the manufacture of chains, and the qualities to be looked for in the material used, the author gives much information as to the methods of testing the work after completion. The author, on the whole, prefers wrought iron to steel, and advocates frequent and careful annealing.

The Manufacture of Tubes.—According to Bock, ‡ the method of manufacturing pipes he now describes was first described by Muntz, who patented it in the United States in 1853. The first five illustrations the author gives are taken from this patent. A hollow ingot was first made, and this was subsequently rolled down after being washed inside with milk of lime to prevent the inner surfaces adhering during the rolling. A divided strip resulted, which it was then attempted to open out into a pipe by further rolling. The inventor did not, however, apply this method to iron—copper, brass, and other copper alloys being only dealt with. This method has of late been taken up by others, and amongst these by Garnier. The latter takes a hollow ingot, and placing inside this two round mandrils, rolls the whole in a suitable mill. The mandrils are stated to be again removed after the rolling. The further application of this process is then dealt with, the manufacture of hollow iron masts being specially considered. For quite a number of tubes, the author observes, the original method in its simplest form is better than any of the so-called improved methods, when it is a case of producing tubes of larger diameter. Masts up to some 100 feet in length may be made in this way in one piece without a joint.

O. Klatte § discusses Bock's paper on the manufacture of ribbed tubing and hollow masts. The author states that he himself originated the process described, and gives further details. Generally speaking,

* *Revue Universelle des Mines*, vol. xlvii. pp. 1-20, with three plates.

† Paper read before the Manchester Association of Engineers, January 1899.

‡ *Stahl und Eisen*, vol. xix. pp. 68-72; eighteen illustrations.

§ *Ibid.*, pp. 233-237; numerous illustrations.

no patents hold good with regard to this general process of manufacture, apart of course from details.

A couple of illustrations are given of the plant at the Alma Tube Works, Walsall, showing the mill for rolling down hollow billets, and taper rolls used for cold-rolling the finer tubes. The process is described.*

Structural Steel.—The *Age of Steel* † points out that iron and steel for constructive purposes are more extensively used than is generally supposed. In the Astor Hotel, New York, the structural ironwork aggregates 10,000 tons, or one-sixth of the weight of the entire building. In a thirty-storey building in the same city the ironwork amounts to 9000 tons. The same conditions obtain in numerous instances throughout the United States, and the tonnage of iron and steel used must be enormous.

Details are published ‡ of the Park Row building in New York, which is 390 feet in height. It consists of 8000 tons of steel and 12,000 tons of other material. Details are given as to its construction. It is pointed out that this total weight of 20,000 tons is just that of the *Kaiser Wilhelm der Grosse*, the largest German steamship. The total cost of the building was some £500,000, and that of the steamer about half as much again.

Modern German Bridge Construction.—An account of modern bridge construction in Germany is given by Rieppel.§ The author compares German methods of construction with those in use in other countries. The use of nickel steel for chains is also referred to in this connection. The architecture of modern German bridges is discussed by Frentzen.||

The new Rhine bridge near Düsseldorf is described by Krohn,¶ who also deals historically with iron bridges in general.

Iron Bridges in Austria-Hungary.—M. Foerster** describes and illustrates a number of iron bridges in Austria-Hungary. Among

* *Engineering*, vol. lxi. pp. 825-826.

† November 19, 1898, p. 13.

‡ *Scientific American*; *Stahl und Eisen*, vol. xix. pp. 97-99; four illustrations.

§ *Stahl und Eisen*, vol. xviii. p. 962.

|| *Ibid.*, p. 962.

¶ *Ibid.*, pp. 1102-1103.

** *Ibid.*, vol. xix. pp. 138-143; nine illustrations.

those described are the bridges over the Theiss at Tokay, over the Oder at Schönbrunn, and the Schwurplatz bridge at Buda-Pest.

The Use of Iron for Sails.—At the Krupp Germania Works at Gaarden it is stated that an iron yacht-sail is now in process of manufacture. It is anticipated that iron of about 0·02 inch in thickness is capable of being utilised for this purpose.*

Use of Superheated Steam in Ironworks.—H. Hoff † discusses the various methods which are in use for the production of superheated steam, and the use that is made of it. Incidentally the author observes that at the Hörde Ironworks there has now been in operation for some time a gas-engine of 600 horse-power, which is driven by blast-furnace gas, after it has been subjected to purification to free it from entangled dust. The author still foresees an important field of progress for the steam-engine, pointing out that heretofore only “saturated” steam has been chiefly employed in steam-engines, provided this is replaced by superheated steam. The material used in the superheaters employed is iron or steel. Copper is not suitable. The tensile strength of weld or ingot iron scarcely diminishes up to a temperature of 400° C.; indeed it is at its maximum tenacity at temperatures between 250° and 350° C. Cast iron increases in strength slightly up to 386° C., and the strength then somewhat diminishes again. Copper, on the other hand, greatly decreases in strength with such increases of temperature. Thus Rudeloff has shown that by raising the temperature of copper from 16° C. to 293° C. its tensile strength diminishes by 50 per cent. Bronze diminishes in strength even more rapidly, although “phosphor-bronze” still retains two-thirds of its original strength at a temperature of 260°. There exist in Germany at the present time over 2000 plants provided with superheating apparatus.

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlvii. p. 89.

† *Stahl und Eisen*, vol. xix. pp. 370–381; twelve illustrations.

PHYSICAL PROPERTIES.

The Microstructure of Iron.—L. Ijain * considers the question of the microstructure of iron, and points out how the mechanical properties of the metal are intimately connected with them. He refers to the work of those who have devoted so much attention to the investigation of this subject, and then considers separately the various constituents of iron, such as ferrite, troostite, &c. Investigations of rolled iron made by the author show in a marked manner that the tensile strength increases with an increase in the percentage of perlite and the size of its grains, the elongation at the same time diminishing. Steel with a tensile strength of less than 38 to 41 tons per square inch is, however, an exception. It differs in a marked way as regards its microstructure from steels with a higher tensile strength. In the former the perlite grains look like small black points scattered in a light groundwork of ferrite, while in the stronger steels they appear as polygonal granules separated from each other by ferrite lines of greater or less thickness. In more than twenty sections the area of these perlite grains was measured, and an attempt made to see how their variations in size compared with the variations in the tensile strength of the steel. The results are plotted in the form of curves, and these show in a very marked manner that as the size of the grain increases so does the tensile strength of the metal. The author believes that the reason for the want of accord between his results and those of Sauveur lies in the fact that the samples the latter worked with were not such as to enable him to obtain adequate results as regards the variations observable in the tensile strength. The author recognises the connection between the tensile strength and the general composition of the metal, but this does not affect the question. He finds that hardening increases the size of the perlite grains. The method of preparing the sections and test-pieces is described. For etching purposes the author used 2 per cent. bromine water, and he considers that the microscope as arranged by Martens is very well adapted for use in this connection. Microphoto-

* *Baumaterialienkunde*, vol. iii. pp. 105-108; eight illustrations.

graphy the author does not, however, approve of, considering that for ordinary purposes sketching is much more applicable.

E. Heyn * gives the results of the microscopic examination of deeply-etched iron sections. Various kinds of ingot iron were polished and etched with copper-ammonium chloride, and the phenomena presented are discussed by the author, frequent reference being made to the work of J. E. Stead on this subject. The paper is illustrated by 124 photographs.

The installation at the Saint-Etienne Steel Works for the microscopic investigation of steel is described and illustrated by F. Périllon.†

Magnetic Properties of Iron and Steel.—A. Durward ‡ gives the results of experiments on the temperature coefficient of certain seasoned hard steel magnets.

B. O. Peirce§ has experimented upon the properties of seasoned magnets made of self-hardening steel.

F. C. Caldwell|| describes some experiments as to the influence exerted by silicon on the magnetic permeability of cast iron. Rochford pig iron—a grey iron from Tennessee—and iron made by the Bessemer process from Lake Superior ores, were employed in the experiments. The specific magnetic resistance proved in low-power fields to be inversely proportional to the percentage of silicon added to the iron by means of an addition of spiegeleisen, and subsequently determined by analysis. It was possible, therefore, to represent these results by a straight line. In higher power fields this straight line became a hyperbola, but this could again be replaced by a straight line when the percentage of silicon varied from 1·8 to about 3·5. An addition of silicon up to 3 per cent. in quantity made the iron softer, but more than this percentage made it harder again. The maximum degree of magnetic permeability appeared, however, to require a larger percentage of silicon than 3.

The permanent torsion of a magnetic steel wire has been determined by G. Moreau.¶

The magnetic properties of nickel steel are described by E. Dumont.**

* *Mittheilungen aus den Königlichen technischen Versuchsanstalten zu Berlin*, vol. xvi. pp. 310-331.

† *Bulletin de la Société de l'Industrie Minérale*, vol. xii. pp. 469-480.

‡ *American Journal of Science*, vol. v. pp. 245-256.

§ *Ibid.*, pp. 334-342.

|| *Electrical World*, vol. xxxii. p. 619.

¶ *Comptes Rendus de l'Académie des Sciences*, vol. cxxviii. pp. 292-294.

** *Archives des Sciences Physiques et Naturelles*, Geneva, vol. v. pp. 331 and 426.

The Electric Resistance of Steel.—According to H. Le Chatelier,* the electric resistance of steel to the passage of an electric current increases almost exactly proportionately with the carbon percentage. Hitherto such experiments have dealt chiefly with extra mild telegraph steel, and have shown that the resistance of the metal depends almost entirely on the percentage of manganese present. In Le Chatelier's experiments square pieces of steel 7·87 inches in length and 0·39 inch side were annealed for several hours to about 600° C. These were subsequently examined, with the following results. The resistances are given in micro-Ohm cubic centimetres :—

| Carbon Influence. Resistance. | Percentage Composition. | | |
|----------------------------------|-------------------------|------------|----------|
| | Carbon. | Manganese. | Silicon. |
| 10·0 | 0·06 | 0·13 | 0·05 |
| 12·5 | 0·20 | 0·15 | 0·08 |
| 14·0 | 0·49 | 0·24 | 0·05 |
| 16·0 | 0·84 | 0·24 | 0·13 |
| 18·0 | 1·21 | 0·21 | 0·11 |
| 18·4 | 1·40 | 0·14 | 0·09 |
| 19·0 | 1·61 | 0·13 | 0·08 |

The increase in resistance averages 7 micro-Ohms per 1 per cent. carbon by weight, or 1·5 micro-Ohm for one carbon atom to 100 atoms of iron and carbon. Annealed steel consists of a mixture of ferrite (pure iron) and cementite (Fe_3C). From the author's results he calculates the relative resistance of these two constituents to be 9·5 for the ferrite and 45 for the cementite.

The next question dealt with is the influence of the silicon present in the metal. The author's results were as follows :—

| Silicon Influence. Resistance. | Percentage Composition. | |
|-----------------------------------|-------------------------|----------|
| | Carbon. | Silicon. |
| 12·5 | 0·2 | 0·1 |
| 38·5 | 0·2 | 2·6 |
| 15·8 | 0·8 | 0·1 |
| 26·5 | 0·8 | 0·7 |
| 33·5 | 0·8 | 1·3 |
| 17·8 | 1·0 | 0·1 |
| 25·5 | 1·0 | 0·6 |
| 32·0 | 1·0 | 1·1 |

* *Bulletin de la Société d'Encouragement*, vol. iii. pp. 743-744.

These figures point to an increase of 14 micro-Ohms for 1 per cent. silicon, or to 7 micro-Ohms for 1 silicon atom in 100 atoms of the metal. The resistance is thus much greater than for carbon. The author observes that one is inclined to assume that silicon does not exist in steel as the silicide FeSi_2 , but in a condition of a homogeneous mixture with the hardening carbon.

Manganese, as is known, considerably increases the resistance of steel. This element, isomorphous with iron, forms homogeneous mixtures with it in all proportions. These mixtures can, however, exist in two allotropic and dissimilar magnetic conditions, which possess two very different electric resistances, as the author showed in the case of Hadfield's manganese steel with 13 per cent. of manganese. The results obtained by the author in his present experiments were as follows:—

| Manganese Influence. Resistance. | Percentage Composition. | | |
|-------------------------------------|-------------------------|------------|----------|
| | Carbon. | Manganese. | Silicon. |
| 17.8 | 0.9 | 0.24 | 0.1 |
| 22.0 | 0.9 | 0.95 | 0.1 |
| 24.5 | 1.2 | 0.83 | 0.2 |
| 40.0 | 1.2 | 1.80 | 0.9 |
| 66.0 (magnetic) | 1.0 | 13.00 | 0.3 |
| 80.0 (non-magnetic) | 1.0 | 13.00 | 0.3 |

These numbers indicate a general increase in the resistance of about 5 micro-Ohms for 1 per cent. of manganese. For magnetic manganese steel, obtained by heating the non-magnetic steel for two hours to 550°C. , the resistance is only 3.5 micro-Ohms.

Nickel forms isomorphous mixtures with iron, and causes a considerable increase in the electric resistance. This steel, like the manganese steel, forms two varieties dissimilar magnetically, which also show different resistances. The increase in resistance, calculated for 1 per cent. of nickel, varies exceedingly with the percentages of nickel and carbon and the allotropic condition of the alloy. With percentages of nickel below 5 per cent., this increase varies from 3 to 7 micro-Ohms.

Chromium, tungsten, and molybdenum influence the electric resistance only in a very slight degree. For percentages below 3, the only ones the author examined, the increase cannot be accurately measured. The presence of silicon and manganese exert equal or greater influence, even when present in the usual low percentages of 0.5 or less, than ten times larger quantities of these other three elements. The slight in-

fluence they exert would lead to the assumption that they exist in the mass of metal not alloyed but in an isolated condition. This view agrees with the chemical results obtained by Carnot.

Professor W. F. Barrett* has investigated the thermo-electric behaviour of some samples of nickel and manganese steel which had a very high resistance. With iron as the second element, they gave an almost constant electro-motive force between 300° C. and 800° C.

Expansion of Steel Erections by the Sun's Heat.—The daily movements of the Eiffel Tower under the influence of the sun's heat have been carefully studied and measured. It is found to twist from east to west, its point forming an arc with a diameter of about four inches. In summer the movement is naturally greater than in winter. The lowering of the temperature after sunset causes the tower to untwist again, the result being that this enormous construction is in constant movement due to this cause.†

The Hardening of Steel in Ancient Times.—O. Vogel‡ discusses the hardening of steel in ancient times, and the views that were held as to the cause of the hardening. The art of hardening steel is of extreme antiquity. Homer describes it, and he also knew the coloration tints that result on tempering. Pliny the Younger, too, describes the hardening of steel in his thirty-fourth book. He mentions various places where the water was celebrated for its hardening of steel, Bilbilis and Turiasso in Spain and Comum in Italy, "although there are no iron ore mines at these places." Not only did he know of water-hardening, but he also observes that the finer class of tools were hardened in oil, to prevent them becoming so brittle as would result from hardening in water. The Roman poet Lucretius also refers to the hardening of steel by plunging the heated metal into water.

The German tribes, too, had from high antiquity been acquainted with the hardening process. Whether or not the cementation process was known in those days cannot be said with certainty, though it would seem that this was so.

The ancient smiths laid particular stress on the value of the water used in the hardening process on the results attained. Thus in his sermon on "iron and steel" in 1558, the celebrated preacher

* *Scientific Proceedings of the Royal Dublin Society*, February 22, 1899.

† *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlv. p. 60.

‡ *Stahl und Eisen*, vol. xix. pp. 242-247.

Mathesius observed that one water will harden better than another, for which reason the armour made at "Insbruck" was so well hardened. The art of hardening weapons, &c., was always in ancient times held to be a secret craft, and even now-a-days at Solingen they profess to possess certain secrets relating to hardening. So secret, indeed, was it considered, that apprentices had to take an oath not to leave the country, and not to teach the craft to any one else except their own sons. Some curious old recipes for hardening are given by the author.

The first to really study the hardening process was Reaumur, but his views at first sight appear crude, inasmuch as they were dependent on the then existing theories as to the constitution of metals. Still, as Beck has pointed out, they are in some ways remarkably close to those now held. After Reaumur came Rinman and a number of others whom the author names.

In conclusion the author observes, that although since the times of Reaumur and Rinman many have attempted to finally settle the question of the hardening process, it is still not altogether understood, and even now there are four different theories to account for the hardening, each of which has its own particular body of supporters.

The Strains in Completely Hardened Steel.—O. Thallner* observes that Reiser was the first to point out that the strains produced in steel by hardening, and deducible from the changes in volume of the metal, are the cause of the hardening, and Barus and Strouhal proved that in hardened steel considerable differences both in volume and specific gravity existed between the strongly-hardened outer layers and the less strongly-hardened inner layers, and that the strains resulting were the causes of cracks in hardening. The author made a number of experiments for the purpose of ascertaining the influence exerted by manganese and by silicon on the changes in volume during hardening, and these led the author to doubt the accuracy of the existence of pressure strains. Two kinds of strains must exist: (1) those which occur in steel of small cross-section that has been evenly hardened throughout, and (2) those which occur in steel of larger cross-section, due to the unequal changes in volume of the surface and the interior. The first of these also occur in steels of large cross-section and to the greatest extent on the surface. If steel of small cross-section is so hardened that it becomes

* *Stahl und Eisen*, vol. pp. xviii. 935-938.

of the same degree of hardness everywhere, it may still crack, although this cannot be considered as due to pressure exerted by the hardened and contracted outside on the interior. If steel of large cross-section is hardened, cracks may commence at the surface as well as within the metal. It is not possible, however, for such cracks to form within the metal if they are due to pressure exerted by the outer hardened skin on the softer core. So, in accounting for such strains, the author first passes in review the present theories of the hardening process, and, drawing attention to the changes in texture and volume which take place, considers that the strains referred to have their origin in these causes.

In a later paper, O. Thallner * considers the question of the strains that occur in hardened steel of large cross-section. These are due, the author observes, to the changes in volume and in shape that take place during the hardening. He discusses these seriatim, and observes that numerous experiments made at the Bismarck Works have shown that steels of different chemical composition may be divided into two main groups as regards their behaviour during the hardening process: (1) those which become shorter, and (2) those which become either shorter or longer. These two groups are not separated from each other by any definite line of demarcation. It is dependent on the chemical composition, and in the case of pure carbon steels, lies at about a percentage of 0.90 of carbon. In the case of steels of the first group and those of the second which become shorter when hardened, an increase in the thickness and width is always observed. The larger cooling faces always assume a concave form. In the case of steel belonging to the second group which becomes longer when hardened, an increase in the dimensions both as to width and thickness may occasionally be observed, but the larger cooling faces are never concave. They are, indeed, usually slightly convex. A series of results are given of measurements made in connection with five samples of crucible steel and eight of basic open-hearth steel. The former became shorter and the latter longer after hardening. The various kinds of strain which can result are then enumerated and considered.

Relation between Chemical and Physical Properties of Steel.

—W. R. Webster † reviews the attempts that have been made to find empirical rules by which (due allowance being made for heat-treatment

* *Stahl und Eisen*, vol. xix. pp. 318-324; ten illustrations.

† *Transactions of the American Institute of Mining Engineers*, October 1898 (advance proof); *American Society of Civil Engineers*, vol. xl. pp. 449-470.

and mechanical manipulation) the tensile strength of steel may be predicted from its chemical analysis. Most of these attempts involve the assumption of a simple arithmetical addition or subtraction, but no one pretends that this is exactly correct. The effect of one element modifies that of another, so that a comprehensive mathematical formula, even if it could be obtained, would involve very complicated expressions. To trace the history of this investigation, and to show its present condition, numerous extracts are made from the writings of the author and of P. G. Salom, J. Stokes, Gatewood, M. Williams, H. M. Howe, C. E. Stromeyer, Vosmaer, F. Osmond, A. Sauveur, H. H. Campbell, Cunningham, and of others. The possible effect of the various conditions in which carbon exists in steel is discussed, and the bearings of the investigations on different manufactures are dealt with. In twenty-three tables the author has presented the values of carbon, phosphorus, and other elements as given by different investigators, so that different views and opinions are more readily available, and may be combined for further research. The author is of the opinion that the progress already made is along the right lines, and is worthy of more extended attention.

Brinell's chart of changes of fracture and carbon in steel, which first appeared in 1885, and last year was presented to the members at the meeting of the Institute in Sweden, has been republished.*

H. Wedding† discusses the testing of iron used in the mechanical arts. The physical properties of an iron are dependent upon its chemical composition and its microstructure. The latter is again affected by the heat and mechanical treatment received. In preparing the finished article, the manufacturer deals with the chemical composition principally. This being correct, his experience enables him to obtain physical results by proper mechanical manipulation or processes. While a certain variation in composition can be corrected by slight changes in process, this is necessarily risky, and the consumer protects himself by not only physical but also chemical tests. The author now brings up the question of the allowable error in analyses, and states that although Commissions have been appointed in Germany, England, and America, no results are as yet forthcoming which will serve to establish standard methods for determining the various elements found in commercial steel and iron. To show that this limit of error is a necessity, he gives the current variations as

* *Engineering and Mining Journal*, vol. lxvi. p. 755.

† *Baumaterialienkunde*, vol. iii. pp. 161-162.

follows :—Carbon analyses often vary 0·1 per cent. ; silicon, 0·05 ; manganese, 0·5 to 0·6 ; phosphorus, 0·05. These are for steel and iron. Pig and cast irons vary still more. Now, in making steel of specified physical qualities, one must predicate such results on corresponding chemical compositions, and when it is realised that an error of 0·1 per cent. in carbon means a difference of several thousand pounds in the ultimate strength, not to speak of the other elements, the total variations thus traced home to the error in analytical results may assume serious proportions. The recent discoveries, which point to a multiplication of forms in which the various elements may exist, only complicate matters, and the author concludes with an appeal to further the plan of establishing a sidero-chemical laboratory to take up this very question of standard methods of chemical analysis and all that is connected with it.

Baron H. von Jüptner * considers the relationship existing between the chemical composition and the microscopic structure on the one hand, and the physical properties of iron and steel on the other. The existence of a connection between the chemical composition and the physical properties of the different varieties of iron has long been known. The action of the carbon is most marked. As the percentage of carbon increases up to 4·3, so the melting-point of the metal diminishes. Beyond 4·3 per cent. the melting-point again rises. The specific heat of iron increases with the percentage of carbon. No definite rule as to the way the coefficient of expansion by heat is affected by the carbon can as yet be laid down. It has been found to be between 0° and 100°, 0·001208 for iron reduced by hydrogen, 0·001228 for soft iron, 0·001362 for French steel hardened, and 0·001113 for the same steel annealed. For English steel the figure found was 0·001110, and for grey pig iron 0·001075. The conductivity for heat and electricity diminishes, as a rule, with an increase in the carbon percentage. The tensile strength increases with an increase in the carbon percentage up to a certain limit, and then rapidly diminishes. The maximum strength appears to be attained with a carbon percentage of 0·9. The influence of carbon on the modulus of elasticity appears to be subject to no definite rule. The malleability and weldability diminish in general with an increasing percentage of carbon, while the hardening capacity increases, attaining a maximum when the percentage of carbon is about 2.

With regard to the influence exerted by other elements, the

* *Stahl und Eisen*, vol. xix. pp. 237-242 and 278-283.

author observes that Roberts-Austen has studied the influence exerted by the atomic volume of the added element on the physical properties of the metal to which it is added, finding that when the atomic volume of the added element is less than that of the element to which it is added, the tensile strength and elongation increase, while the reverse is the case if the atomic volume is higher. The author applies this law in the case of iron. It is, of course, only of limited application, as it assumes that the added element enters into no chemical combination, but remains as such in the metal to which it is added; and further, it only applies to small additions and not to large percentages. In the case of iron, the elements occurring with this metal that have lower atomic volumes than it itself possesses are carbon, boron, nickel, manganese, and copper, while chromium, tungsten, aluminium, silicon, arsenic, phosphorus, and sulphur all have higher atomic volumes.

The author gives a number of formulæ for the calculation of the melting-points of different kinds of iron and steel.

Dealing next with the influence exerted on iron and steel by thermal and mechanical treatment, the author refers to the well-known differences between a steel in its hardened and in its annealed condition, as well as when cast, hammered, rolled, or otherwise treated. If it is to be attempted to ascertain with any degree of accuracy the relations which exist between the chemical composition and the physical properties of the metal, the thermal and mechanical treatment must undoubtedly receive consideration. This the author has already attempted to do, and he publishes formulæ for use in this connection.

Dealing next with the influence exerted by the different ways in which the various constituents exist in the metal, the author in the first place considers the influence of carbon in its various modes of occurrence in iron. He deals in detail with the influence of hardening carbon, carbide carbon in various forms, graphitic temper carbon, graphite, and diamond. Graphite, diamond, and temper carbon only affect the mechanical properties of iron in so far as by its presence the mass of the metal in a given cross-section undergoes diminution. The presence of graphite increases the quantity of heat necessary for the fusion of the iron. The presence of hardening carbon increases the tensile strength, limit of elasticity, and hardness, but diminishes the elasticity and the reduction of area. Carbide carbon acts inversely to the action of hardening carbon.

Phosphorus occurs in iron in at least two forms, apart from its

being contained in slag inclusions. One of these two forms consists of granular segregations possessing the composition shown by the formula Fe_3P , or Mn_3P_2 , both being insoluble in dilute acid. These are described as the "indifferent" or "phosphide phosphorus." The other form is the "dangerous" or "hardening phosphorus," and occurs disseminated throughout the main mass of the metal, escaping as PH_3 , when it is treated with dilute acid. This latter form appears to have some connection with the appearance of cold-shortness.

The various other impurities in iron probably all occur in it in at least two different forms, and consequently exert different influences according to which form is present. This subject of research is still, however, but little understood, notwithstanding its importance. The sulphur contents in iron appear to occur in several different forms. These include (1) a compound which is decomposed by dilute acids yielding H_2S ; (2) a compound which on treatment with dilute acid yields the volatile compound $\text{S}(\text{CH}_3)_2$; and (3) in a form which, under similar conditions, remains behind in the undissolved residue as an organic compound. These two latter forms may, however, possibly represent decomposition products of one and the same sulphur compound.

Manganese, nickel, copper, and titanium appear to occur in iron in a dissolved form, but a part of the manganese may occur as a silicide or sulphide.

Chromium occurs in iron alloys in two typical forms: (1) disseminated (dissolved) throughout the main mass of the iron, and therefore easily soluble with it in acids, and (2) separated in the form of acicular crystals, which are only attacked with much difficulty by acids. These acicular crystals are chromium iron carbides, the composition of which varies with the percentage of chromium present. Up to now the following different compounds have been determined:— Cr_3FeC_2 in ferrochrome containing 50 per cent. of chromium, and $\text{Cr}_2\text{Fe}_7\text{C}_3$ in chrome steel containing about 13 per cent. of chromium. Tungsten and molybdenum occur as Fe_2W or Fe_3W and Fe_3Mo_2 .

Of iron itself four different allotropic forms have been believed to be observed, and it occurs also in combination with carbon. Recent investigations of Saniter would appear to prove the existence of two such allotropic forms of iron.

Dealing next with the connection between the microscopic texture and the physical properties of the metal, the author first considers what are the micrographic constituents. These in the case of a pure

carbon iron consist of the following:—(1) Hollows, α with rough surface, either empty or containing air, and β with a smooth surface—these latter contain hydrogen and carbon monoxide; (2) slag inclusion; (3) graphite; (4) ferrite or pure iron; (5) cementite, the carbides; (6) martensite, probably a solution of iron carbide in iron, and forming its hardest constituent; (7) austenite, a high carbon iron alloy, and possibly a solution of carbon in iron; (8) pearlite, a mixture of ferrite and cementite; (9) sorbite, occasionally occurring with pearlite, and being possibly residual martensite which had not had time to change into ferrite and cementite; and (10) troostite, found as thin layers between the martensite and cementite, possibly bearing the same relation to these as sorbite does to ferrite and cementite. The author then proceeds to show the connection which exists between the occurrence of these several constituents of the metal and its chemical composition, and the thermal treatment to which it has been subjected. He next passes to a consideration of the influence exerted by these various substances on the physical properties of the metal. All experience, he observes, shows that the presence of martensite causes the metal to possess the properties which are characteristic of hardened steel, while that of pearlite causes the metal to possess the properties shown by annealed steel. Steel with from 0·8 to 0·9 per cent. of carbon consists entirely, according to the treatment to which it has been subjected, of martensite or pearlite, and the maximum tenacity shown by steel when the percentage of carbon reaches from 0·8 to 1·0 is evidently in connection with this. The author enumerates the various elements which appear to increase the strength of steel, and also those which appear to diminish it, the ways in which this is done being also passed in review.

Next the author deals with the size of the grain and the influence this exerts on the physical properties of the metal; and then, in conclusion, he observes, that although very much still remains to be done to make perfectly clear the connection which exists between the chemical composition, the micrographic texture, and the physical properties of steel, yet sufficient is already known to obtain a fair idea on this point even at the present time. It is becoming more and more clear that metallic alloys are to be considered as solutions—liquid ones when molten, and solid ones when the metal has solidified. As the temperature rises and falls, so the degree of solubility increases or diminishes, and when the temperature is low enough the dissolved constituents begin to separate out. With still lower temperatures

their separation becomes more and more pronounced, and the substances so separating out become chemically of a more and more complicated character. Finally, a temperature is reached at which both the constituents of the solution solidify together. These eutectic alloys are represented in the case of steel by perlite.

Absorbed gases must also be looked upon as solutions of the gases in the metal. These too separate out at certain temperatures and cause the formation of bubbles. Even chemical compounds, such as manganese sulphide, ferrous oxide, manganous oxide, and perhaps slags, may occur in a state of solution in the metal and separate out at certain temperatures. While in liquid solution complete separation is possible, this is not the case in solid solutions in which only local separation is possible. One constituent or another forms more or less irregular granules entangled in a meshwork of the other, and must modify, in accordance with its nature and mode of occurrence, the physical properties of the metal. This the author shows diagrammatically.

A paper on the relations of the mechanical properties of steel to the chemical composition has been published by William Minty.*

The Melting-Point of Cast Iron.—R. Moldenke,† with the aid of a thermo-couple, has investigated the melting-point of cast iron, and shows that the eye is no criterion of the higher temperatures. The thermo-couple used had its tip protected by asbestos and a clay cap. The appliances used are illustrated, and it is stated that the sensitiveness of the couple, even though protected by a refractory material, is such that plunging it cold into the melted iron the correct reading is obtained in $1\frac{1}{4}$ minute. When properly heated up to redness beforehand, however, this time is reduced to not many seconds. For the test a piece of the pig of full section and about 5 inches long was melted down in a small assay furnace. The thermo-couple was placed in a hole in the metal which had been bored for analysis. The following general observations were made:—The white irons held their shape, the iron running from the sides and bottom freely, leaving smooth surfaces. The grey irons became soft, dropped in lumps, leaving a ragged surface. Ferro-manganese samples became soft and mushy, exhibiting a consistency of putty before finally running down; while ferro-tungsten behaved in a most marked manner. As it melted

* *Transactions of the Engineering Society of the School of Practical Science, Toronto*, No. 11, pp. 145-153.

† *Journal of the American Foundrymen's Association*, vol. v. pp. 282-292.

it acted like white iron, but instead of chilling quickly, it ran through the coke, coming down the spout in thin streams like white-hot quicksilver, only settling after collecting in a pool in the pan of sand. Over seventy melting-points of iron, steel, and other materials, with the analyses, are given in tabular form, and show that with few exceptions the melting-points increase as the combined carbon diminishes, this being the case independent of the amount of graphite present.

Endurance of Steel Bars.—E. G. Coker* describes a series of experiments upon two mild steel bars subjected to repetitions of torsional stress. His results show that with mild steel bars subjected to tensile stress followed by annealing under conditions described by him :—

1. The total extension is about four times that of a bar broken in the ordinary manner.

2. The breaking-down stress is of an approximately uniform value during the first stage when the bar has not deviated much from its original form, followed by a considerable divergence, the general tendency of which is to a considerable rise in value.

3. The work done on a bar under the given conditions is approximately one-half of that done upon a bar broken under tensile stress in the ordinary manner.

The Elastic Limit.—J. A. Ewing† discusses the problems of elasticity and elastic strain, and shows that very delicate instruments are required for the correct determination of Young's modulus of elasticity or the stretch modulus, and the modulus of rigidity or the shear modulus. After describing extensometers designed by Bauschinger and by Unwin, the lecturer went on to show several forms of an extensometer of his own invention which had been found at once convenient and accurate in practice. This instrument is entirely self-contained, and is attached to the piece under test by two set-screws at the ends of the length on which the observation of extension is to be made. In its usual form for tension tests, it reads to one fifty-thousandth of an inch, but in a special form designed for measuring the elastic compression of short blocks, the readings are taken to $\frac{1}{250000}$ inch. Other pieces of laboratory apparatus designed for measuring the elastic modulus by bending and by twisting were

* *Minutes of Proceedings of the Institution of Civil Engineers*, vol. cxxv. pp. 294-299.

† Paper read before the Institution of Junior Engineers, January 1899.

also described. Reference was then made to the very imperfectly elastic condition into which iron or steel is thrown by straining beyond the ordinary limit of elasticity. Immediately after being overstrained and when the load is removed, the piece on being reloaded does not follow Hooke's law at all, and cannot be said to have any elastic limit. But as time passes the elasticity comes back, and after an interval of a few days in the case of wrought iron, or of many weeks in the case of steel, it is found that the material has practically perfect elasticity up to a limit which may be much higher than the primitive elastic limit. This recovery of elasticity had formed the subject of investigation by Bauschinger. The curves showed that there was much hysteresis in the relation of strain to load, in overstrained metal, when cyclic processes of loading were gone through before the recovery of elasticity had taken place. J. Muir* had, on the lecturer's suggestion, tested the effect of heating overstrained metal to moderate temperatures, and had made the remarkable discovery that a bar of overstrained iron or steel is completely restored to a perfectly elastic state by being exposed for a few minutes to 100° C. By alternately heating the bar in this way, and loading it just beyond its new limit of elasticity so as to slightly overstrain it, a piece of mild steel may be made to break with scarcely any total elongation, and to show an extraordinarily high range of elasticity and ultimate strength. Steel reduced to this semi-plastic state by overstrain recovers slowly by the lapse of time, and by repeated overstrain the yield-point is raised. The recovery takes place practically at the same rate, both under stress and free from load. Three or four minutes at 100° C. allows perfect recovery, and even at lower temperatures the normal condition is slowly reached. Mechanical vibration has an opposite effect, and magnetic agitation is without action.

Testing Machines.—F. A. Riehle† reviews the subject of testing machines, and mentions a very small one made for testing pieces about the thickness of the lead in a lead pencil. This is used by P. H. Dudley for testing samples cut from rails, and is so small that it may be carried.

A. Martens,‡ in a very important and elaborate work, deals with

* *Proceedings of the Royal Society*, vol. lxiv. pp. 337-340.

† Paper read before the Foundrymen's Association, Philadelphia, March 1, 1899.

‡ *Handbuch der Materialienkunde*, Part I., Berlin, 1898, p. 516, with 514 figures in the text and 20 plates. Price £2.

the general characteristics of building materials, with the methods of testing, and with the appliances used for this purpose. Each of these subjects is dealt with very fully, and in connection with testing machines it is pointed out that if these are accurate to within 1 per cent., that degree of accuracy is adequate.

Recent testing machines are described by Frémont* and by G. Charpy,† and the methods of determining the strength of materials are dealt with by A. H. Jameson.‡

Tests of Cast Iron.—The preliminary results of the tests made by the Foundrymen's Committee on standard bars have been published. The iron used was an ingot mould iron, soft Bessemer mixture, and on analysis showed : §—

| Total Carbon. | Graphite. | Silicon. | Manganese. | Phosphorus. | Sulphur. |
|---------------|-----------|----------|------------|-------------|----------|
| 3·87 | 3·44 | 1·67 | 0·29 | 0·095 | 0·032 |

No less than 280 tests were made on bars of various sizes, ranging from $\frac{1}{2}$ to 4 inch square and round, cast in dry and in green sand, machined and not machined, the tests including transverse, tensile, and compression tests. The results are given.

A. Martens|| considers testing methods generally, and also discusses the question of standard methods for the testing of cast iron. The author deals first with the paper by Moldenke,¶ as discussed by Ledebur, on the testing of cast iron, and then proceeds to consider the question at greater length. He questions whether any very important value should be attached to tensile tests in the case of cast iron, and whether it would not be better to eliminate them altogether, except in special cases, the bending test of itself giving a good idea of the character of the metal, especially if in addition percussion tests are also made use of to show the degree of fragility of the metal. He thinks that given such tests, the question of percentage limits in the case of the chemical composition need not be pressed in general practice.

* *Mémoires de la Société des Ingénieurs Civils*, vol. li. pp. 506-524.

† *Revue Mécanique*, 1899, pp. 44-79.

‡ *Minutes of Proceedings of the Institution of Civil Engineers*, vol. cxxxiv. pp. 352-362.

§ *American Manufacturer*, vol. lxiv. pp. 214-217.

|| *Zeitschrift des Vereines deutscher Ingenieure*, vol. xlii. pp. 1326-1330 and 1348-1350; ten illustrations.

¶ *Journal of the Iron and Steel Institute*, 1898, No. II. p. 533.

R. Moldenke* comments upon the views expressed by Martens on the methods of testing cast iron.

G. C. Henning† draws attention to the objects of the International Association for testing materials.

Test of Old Iron.—The result has been published‡ of a test of a bolt taken from the hull of the *Canton*, an old East Indiaman, which was used as a dry dock at Limehouse. The tensile test showed 20·82 tons per square inch ultimate strength, elongation $18\frac{1}{4}$ per cent. on 4 inches, and reduction of area 36 per cent. This iron must be over a hundred years old.

Nickel Steel Tests.—A series of exhaustive and instructive tests with nickel steel has been undertaken§ at the Charlottenburg Testing Institution, near Berlin. The chemical composition of the blocks used for testing varied between 99·6 and 0·33 per cent. of iron with 0·05 to 98·4 per cent. of nickel, the percentage of other ingredients, such as cobalt, copper, manganese, aluminium, and sulphur, being very small. The percentage of cobalt varied from 0·01 to 1·03 per cent., and increased with the percentage of nickel. The analyses showed that the actual percentage of nickel hardly varied perceptibly from the intended percentage. The strength tests showed that when the percentage of nickel increased from 0 to 8 per cent., the limit of elasticity increased from 9·21 to 27·9 tons per square inch, the tensile strength from 20·3 to 35·5 tons, whilst the elongation decreased from 30 to 10 per cent. The greatest strength is thus found with 8 per cent. nickel. With more nickel the conditions become irregular. With 16 per cent. of nickel the tensile strength is 26 tons, but the elongation is not even 1 per cent., so it is extremely brittle. With 30 per cent. of nickel the tensile strength has gone down to 6·35 tons, and the elongation is only 2 per cent. With 60 to 98·5 per cent. of nickel the tensile strength ranges between 24 and 19 tons, and the elongation 36 and 17 per cent. As regards the fractured surface of the various alloys, with 0·5 per cent. of nickel it is porous, but it becomes close with 1 per cent. of nickel. With 3 per cent. of nickel the fractured surface is fine in the grain, but with an increasing percentage of nickel it becomes more and more coarse in the grain,

* *Iron Trade Review*, January 19, 1899, pp. 10–11.

† *Engineering Magazine*, vol. xvii. pp. 122–130.

‡ *Engineer*, vol. lxxxvi. pp. 450–451.

§ *Engineering*, vol. lxvi. pp. 862–863.

eventually showing needle-shaped crystals. As an exception, it may be mentioned that with 60 per cent. of nickel, when the strength condition again became normal, there is a fine grain. The results obtained on compression are quite similar, and the same applies to nickel steel with less than 16 per cent. of nickel. This alloy can very well be hammered at temperatures ranging between 550° and 750° C., which is not the case with a higher percentage of nickel. It will only stand rolling when the percentage of nickel is not more than 4 per cent., and cracks or tumbles to pieces when the percentage of nickel is larger.

Some notes have appeared * on recent advances in the manufacture of boiler and pipe materials. Reference is made to the use of nickel steel and to various physical and other requirements in recent specifications.

Some results of tests of nickel-steel are included in G. Charpy's paper† on the influence of temperature on the properties of alloys; and in an exhaustive research by F. Osmond,‡ the critical points at which magnetism disappears during heating, and those at which it reappears on cooling, have been determined for iron-nickel alloys containing 50 to 100 per cent. of nickel.

The Constitutional Causes of Tendency to Fracture in Iron and Steel.—J. E. Stead§ discusses some of the apparent causes which lead to fracture in cast iron, wrought iron, and steel. The conclusions arrived at were, as far as regarded cast iron, that (1) the lines of fracture in grey metal followed the lines or curved plates of graphite; (2) the lines of fracture in white iron passed through the hard carbide of iron; (3) in the intermediate qualities the fractures passed between the graphite plates and the carbide of iron.

In respect to wrought iron it might be said—(1) That it was made weak and easily fractured by the presence of phosphorus. It was toughest when that element was absent, and gradually became more and more fragile as it increased, but by proper treatment the same phosphoric iron might be stronger than if no precautions were taken. (2) That the cinder in well-cleaned iron caused material weakness if the seams were at right angles to the direction of the strain. In bars

* *Journal of the American Society of Naval Engineers*, vol. xi. pp. 1-16.

† *Bulletin de la Société d'Encouragement*, vol. iv. pp. 191-221.

‡ *Comptes Rendus de l'Académie des Sciences*, January 30, 1899.

§ *Proceedings of the Cleveland Institution of Engineers*, 1898, pp. 12-37.

and rails the seams were usually in the same direction as the material was strained in use, and in such cases the cinder reduced the strength probably by little more than the proportionate area occupied by the cinder. It certainly reduced the tendency of the iron containing it to corrode. It possibly assisted in retarding the growth of cleavages and flaws which started at the external surface. (3) That grossly crystalline structure was coincident with weakness.

The causes tending to fracture in steel were probably (1) the presence of a scoriaceous envelope which occasionally surrounded the grains of steel in steel which had not been pressed or forged, and the presence of envelopes of cementite round the grains in high carbon steels; (2) a coarse crystalline structure; (3) the alterations in the structure developed by crushing or hammering the material cold.

Specifications for Structural Steel.—According to W. R. Webster,* the specifications for American structural steel and rails are, on the whole, very satisfactory, but there are specifications in which the physical and chemical requirements do not agree, or that call for an extremely high elastic limit or other results, which cannot be obtained by the ordinary methods of manufacture and testing.

The quality of steel depends (1) on its chemical composition; (2) on the treatment it receives in the course of manufacture; and we are learning year by year better to distinguish the results due to each. To-day results are obtained that were formerly considered impossible, and the steel is not allowed to cool from the original casting temperature until it is rolled into the finished product. This, of course, is a great saving of fuel, and increases the output. This great advance has been brought about by close observation of the methods of manufacture and the establishment of the relation between the chemical composition and the physical properties. The analysis of each heat is made while the ingots are still in the soaking-pits, and the ultimate strength is estimated from its chemical composition.

Recent careful scientific investigations have given valuable information of the character and properties of steel, but there yet remains the important work of showing the direct relation between the results of these investigations and the every-day processes and results obtained in the mills and shops. There is considerable room for improvement in the ordinary methods of testing structural steel. The conditions

* *Journal of the Franklin Institute*, vol. cxlvii. pp. 1-17; *Engineering Magazine*, vol. xvi. pp. 947-956.

under which tests are made should be reduced to a standard as regards the pulling speed and the relation of the width of test-piece to thickness of the material. About three widths would be sufficient to cover all ordinary thicknesses, and they could be used without materially increasing the cost of the present methods of preparing test-pieces. Some simple machine is required for making impact tests, as ordinary tension tests do not give all the information required as to the quality of the material to resist shock.

Too much importance is paid to the quench bends. In some cases the cold bends have been entirely omitted, and the quench bends considered a reliable test as showing the quality of the material; but this is wrong, as soft steel which has been finished at too high a temperature, and thus rendered brittle, so that it will not stand the ordinary cold bends, may be restored by the heating, and the carbon being so low that the subsequent quenching does not harden this class of material, it then bends 180° flat on itself. Much discussion ensued, and amongst the speakers A. A. Stevenson gave results of tests showing that the strength of railway tire steel is increased by allowing a few days' time to elapse between the time the product is finished and the tests are made.

E. Wood * advocates the more extended use of steel in buildings, and points out its many advantages over cast iron and other structural material, especially as regards columns.

Specifications for the steel to be used in the construction of the New East River bridge at New York have been published.† All steel is to be made in the acid open-hearth by the pig iron and ore process from satisfactory stock. Four grades of steel are specified:—I. Angles, plates, and anchor bolts; II. pins and rollers; III. rivets; IV. castings.

| | | I. | II. | III. | IV. |
|--|----------------------|--------|--------|--------|--------|
| Tensile strength, lbs. per square inch . . . | maximum . . . | 68,000 | ... | 56,000 | ... |
| | minimum . . . | 60,000 | 68,000 | 47,000 | 60,000 |
| Elastic limit, lbs. per sq. in., minimum . . . | | 33,000 | 35,000 | 30,000 | ... |
| Percentage elongation, minimum . . . | | 20‡ | 17‡ | 25‡ | 20§ |
| Silicon | | 0·1 | 0·1 | 0·1 | 0·35 |
| Maximum { | Phosphorus | | | 0·08 | |
| | Sulphur | | | 0·03 | |
| | Manganese | | | 0·50 | |

* Paper read before the Manchester Association of Engineers, November 1898.

† *Iron Age*, February 9, 1899, p. 31.

‡ On 8 inches.

§ On 2 inches.

Steel Rails.—C. P. Sandberg* discusses the advantages of using heavier rails for railways laid with flange rails. In Europe bogie rolling stock is scarcely used for heavy goods traffic, and the axle load is constantly increasing, so that the strength of the road has to be increased. Preferably this is done by increasing the weight of the rails, although some advantage is gained by increasing the number of sleepers or by the use of base plates. The author now, however, abandons his previous advocacy of base plates in favour of heavier rails as the more economical measure. The cost of substituting 80-lb. rails for rails weighing 60 lbs. per yard is estimated, and 100-lb. rails are advocated for fast and heavy traffic. A rail section of 120 lbs. with a 7-inch flange has been designed to carry axle loads of 22 tons, and is stated to be not more expensive than English 85-lb. bull-head rails with chairs.

P. H. Dudley† discusses the results obtained in the past fifteen years with stiff and heavy rail sections. Numerous references are given to American railways using his own or similar sections.

H. W. Verhoop‡ describes his method of testing samples during the manufacture of rails. Several small ingots 2·8 by 2·8 by 4·3 inches are cast from each blow, and are marked on one end. These blocks are hammered out into rods 0·8 inch in diameter, but, in order to save time in working up the test-pieces, recourse was had to rolling for the reduction of the ingot samples. Hardening, bending, and drop tests were carried out on the rails themselves as well as on the hammered and on the rolled tests. In the majority of cases the results were concordant, and showed that the use of the rolled sample ingot was perfectly feasible. The results are given in detail.

At a meeting of the Institution of Civil Engineers, held on January 17, 1899, papers were read on the effects of wear upon steel rails by William G. Kirkaldy, and on the micro-photography of steel rails by Sir William Roberts-Austen.

In the first paper the author recounted how experiments he had carried out on two steel rails which had broken under traffic had led to his devoting special attention to the subject, and to a wider investigation. It was found that the breakage of rails resulted from failure, commencing at the top surface, and not from the bottom, as appeared to be the usual belief, and that the deterioration was confined entirely

* *Engineering*, vol. lxvii. p. 62.

† *Transactions of the American Institute of Mining Engineers*, New York Meeting.

‡ *Baumaterialienkunde*, vol. iii. pp. 148-152.

to the top or running head. The deterioration was of the nature of a mechanical hardening of the surface under the action of the rolling load. In some cases this hardening further developed into a species of disintegration by the formation of minute transverse cracks, which, by gradual deepening, ultimately resulted in failure, unless the rail was removed in time. A description was given of the tests specially devised for ascertaining readily, and in a practical form, the extent of deterioration in worn rails. Briefly, this consisted in bending the rail in reverse directions and comparing the behaviour. It was explained that as the bottom member of a rail was found to be deteriorated in quality by wear, it became possible to determine very closely the original quality of any rail (apart from the loss of substance) by testing it under bending stress in the normal direction—that is, keeping the worn head in compression—also by testing specimens prepared from the bottom member under tensile stress. If no deterioration was present, the rail, when bent with the worn head in tension, would bend to a degree corresponding in its behaviour with the worn head in compression. To illustrate this, examples were given showing the wide divergence in some worn rails between their original properties, as brought out under the normal direction of bending, and their behaviour when the direction of test was reversed. The leading features were illustrated by diagrams. A few representative rails taken under various conditions of service were referred to. On the one hand, in the case of a rail after being subjected to severe brake action, the deterioration was very clearly marked; while on the other hand, in the case of a rail that was under favourable conditions, although after the exceptionally long life of twenty-three years' main-line service, the deterioration was very slight. The author drew special attention to the significance of this latter rail. From the commencement he refrained from taking an alarmist view of the condition of rails, considering that where failures or breakages had occurred, there would be definite and special causes sufficient to account for them. He anticipated that the great bulk of rails, where under favourable conditions as to service, would not necessarily be found in a bad state. Reference was made to a number of other rails found to remain in excellent condition after various lengths of service up to considerable periods of time. Striking instances of very severe and rapid deterioration, accompanied with the development of induced flaws, were mentioned, illustrated with figures reproduced from the original reports. The following questions suggested them-

selves in dealing with this subject :—(1) Did all rails suffer alike as to the nature of the deterioration? (2) Did not the quality of the steel affect the resistance of rails to deterioration? (3) Did not the commencement and progress of deterioration of any rail depend on, and vary greatly with, the nature of the traffic, but still more on the special conditions due to its “situation”? The author classified the conditions due to “situation” as follows :—(a) Effects of wear on rails situated under favourable conditions—for instance, when on the level, straight and free, or nearly so, from stoppages of trains; (b) effects of wear on rails situated under unfavourable conditions—for instance, where subject to brake action more or less severe; (c) effects of wear on rails situated at the starting position of trains, where the skidding or climbing action of the driving wheels of locomotives come into play. Some of the questions were answered tentatively, in so far as appeared warrantable from the data already obtained. Reference was made to the probability that the severe deterioration found in the first broken rails examined was produced by the skidding of wheels during starting of trains. It was stated that there had since been no opportunity of testing any rails definitely known to have been subject to such conditions. A comparison followed of the behaviour of the ordinary form with the deep form of fish-plate joints as regarded relative strength. Comments were made, in passing, regarding the microscopic examination of steel, and the author's reasons were stated for not introducing such when dealing with this subject; also regarding chemical analysis and the use thereof in aiming at reproducing steel found most suitable from rails of known life and satisfactory behaviour. A few observations were offered, in the form of suggestions, as to whether it be practicable to find an alloy of steel which would better resist the induction and the rapid spreading of flaws, the simple or ordinary carbon steel being very susceptible to the rapid spreading of a flaw whenever one was induced, or even by the presence of any defect originally in the steel. Emphasis was laid upon the desirability of obtaining a careful record as to the duty performed by worn rails in all cases where further investigations were carried out.

In the second paper a statement was given of the principles which guided micro-photography of steel rails. The most generally useful information as to the structure of a steel rail was obtained by treating a highly polished surface of the section with an infusion of liquorice in water, which stained the pearlite a dark tint and left the ferrite unacted on. The most convenient magnification was between 100 and

150 diameters. Normal rails were thus shown to consist of patches of pearlite set in ferrite; and although the structure was common to all rails, the ratios of the areas differed widely, the amount of carbon increasing with the area of the pearlite. Micro-photographs were appended to the paper to illustrate the influence of manganese on the structure of the steel. If the ferrite was arranged in large enclosed polyhedrons, the temperature to which the rail was raised before rolling was too high. The strength and extensibility increased as the size of the grain diminished, and closely interlocking ferrite and pearlite was the condition which most favoured the prolongation of the life of the rail.

The report of the Italian Southern Railway Company contains the results of observations made on six different types of rails. The experience of the company tends to show that fractures of rails are generally due to defects in the metal. The normal proportion of such failures is about 1 in 2000 per annum. If above this rate, some abnormal conditions of quality or of local circumstances must be looked for. The wear of the upper surface of the rail is least where the line is open, straight, or on easy curves, and fairly level. The rate of wear increases rapidly in tunnels. The extent of wear alone is not sufficient to determine the presumptive life of a rail, as corrosive action must also be taken into consideration.

Basic Rail Steel.—A. R. von Dormus* deals at considerable length with rail steel, and especially with basic open-hearth steel. He points out that while the production of steel has made enormous strides, improvements in testing methods have not made equal progress, as indeed has been shown by the recent agitation for the unification of testing methods. That this is so, the author shows by reference to results observed in practice. Micrographic analysis would be a most valuable addition, but is still in too undeveloped a condition to admit of its general adoption in practical work. In connection with this question of testing, the publications of Ast, Barba, Schrödter, and others are referred to, and the conclusions arrived at by the Congress for the unification of testing methods are given. One of the more important points brought out at the Stockholm Conference in connection with this question of testing, the author thinks, was the general admission as to the want of homogeneity apt

des Oesterreichischen Ingenieur- und Architekten Vereines, vol. 1. pp. 635-640, 648-653, 665-671, 678-684, and 697-702; sixty-one illustrations.

to be shown by ingot metal. The determination of this in connection with rails has long been held a matter of importance, as the author shows, and has been the subject of important investigations. The views of Ledebur and Stein as to the effect of mechanical treatment are fully considered, the formation of "cores" being particularly referred to. Views on this point, the author observes, are still confused. Some attribute too great an influence to the mechanical treatment, and others too little. The truth probably lies between the two. Tetmajer's investigations are also considered in much detail. The requirements for a good rail steel are of two kinds. In the first place stands its safety in practical employment, and in the second comes its degree of economy when in use. These two are, within limits, not antagonistic, and are best obtainable by endeavouring to obtain a metal (1) which shall possess a chemical composition related to the use to which it is to be placed; (2) with as homogeneous a structure as possible; (3) of such a nature that it shall be affected to but a minimum extent by low temperatures or external stresses; and (4) which shall combine adequate toughness with a maximum degree of hardness.

Dealing first with the question of the chemical composition, the author gives as a matter of historical interest the analysis of the first Bessemer steel rail. This was made at Dowlais in 1856, and contained:—

| Carbon. | Sulphur. | Phosphorus. | Iron. |
|---------|----------|-------------|---------|
| 0·080 | 0·162 | 0·428 | 99·330. |

There are also traces of silicon, arsenic, and manganese. The bad influence exerted by sulphur and phosphorus was not known at that time, and this led to the abandonment of this metal for rails at the works in question. Experiments made by Dudley in 1879, in connection with the Pennsylvania Railway Company, led him to conclude that good rails contained less, and bad ones more, than 1 per cent. of impurities. As a result the railway company named subsequently specified that the metal supplied them for rails should contain from 0·25 to 0·35 per cent. of carbon, from 0·40 to 0·30 per cent. of manganese, and not more than 0·10 per cent. of phosphorus or 0·04 of silicon. These rails did not prove altogether satisfactory, however. The author then proceeds to pass in survey a number of statements which have been made in connection with this subject from time to time, giving references to the papers quoted from. He observes that these show considerable differences of opinion both as

to the hardness of the rails to be used and their chemical composition generally. The only point on which there seems general accord is the dangerous influence of a high contents of phosphorus, and there is an evident desire to keep this as low as possible in rail steel. In recent years there is an evident appreciation of harder rails noticeable, due to the fact that it has become possible to manufacture harder rails of a tougher and safer character. It is not possible to lay down any definite general rule, the author thinks, as to chemical composition, except in so far as to require certain elements to be kept down below definite limits. Still for basic open-hearth steel the author considers the following a satisfactory percentage composition :—

| Carbon. | Manganese. | Phosphorus. | Silicon. |
|--------------|--------------|--------------|---------------|
| 0.25 to 0.50 | 0.80 to 1.50 | 0.00 to 0.08 | 0.00 to 0.10. |

The desired degree of hardness is best obtained by varying the percentage of carbon. For double-headed, broad-footed rails the author considers this might be from 0.45 to 0.50, and for other broad-footed rails with a weight of about 70 pounds per yard from 0.35 to 0.40.

Dealing with the influence exerted by the different elements, he first refers to phosphorus. This makes ingot metal cold-short, especially at low temperatures, and this influence increases with an increase in the percentage of carbon. At the conclusion of the basic open-hearth process, the bath of metal usually contains less than 0.02 per cent. of phosphorus, and this is by the subsequent recarburisation rarely increased above 0.03 per cent. According to the investigations of Schneider and Jüptner, the phosphorus occurs in the ingot metal in two forms, as Fe_3P or Mn_3P_2 , in granular form scattered throughout the main mass of the metal, or in another form, as yet not definitely understood, more or less evenly distributed throughout the metal. The former kind is entirely without influence, or almost so, on the mechanical properties of the metal, while the latter affects them seriously. Manganese forming these granules of Mn_3P_2 helps to counteract the influence of the phosphorus, but despite this every effort should be made to keep down the phosphorus contents to the smallest practicable minimum. The phosphorus in steel shows marked liquation phenomena, and may lead to considerable differences from the average percentage. This maximum permissible percentage of 0.08 should therefore also refer to the core steel of the upper end of the ingot.

With regard to the influence exerted by silicon, the views held still vary very greatly, and while some things would point to its being an altogether objectionable constituent, there are yet other cases which would seem to show that a moderate silicon contents is an advantage. It slightly hardens, and influences the tensile tests advantageously, but diminishes the resistance under percussive tests, especially at low temperatures. In the presence of a considerable percentage of carbon, the silicon must not exceed a certain maximum. A distinction must, however, be made between the silicon which was always present in the steel bath and that which is added at the end for the purpose of obtaining sound castings. At the end of the open-hearth process the bath of metal contains only traces of silicon, and no more of this element should be added than may be necessary to produce sound castings. In any case, the finished product should not contain more than 0·1 per cent. of silicon.

With regard to manganese, a small percentage of this element is very generally considered necessary in ingot metal, though great differences of opinion exist as to the percentage that should be present in rail steel. According to the way the metal is made, the finished steel bath contains more or less dissolved ferrous oxide, and this has to be got rid of before a useful metal can result. As deoxidising materials, carbon, manganese, silicon, and aluminium are employed. The more of these is added, the more complete is the degree of deoxidation; but it is only in the case of manganese that any excess so added is not a disadvantage, but even an advantage. An excess of manganese makes the steel much tougher for an equal degree of hardness. It keeps the carbon in the form of hardening-carbon. It exerts, therefore, a hardening influence, and produces a fine grain. It tends to counteract, too, the influence of a higher percentage of phosphorus, silicon, and sulphur, and gives denser castings. It is often objected that the manganese is unequally distributed in ingot metal, but the facts are not favourable to this view. Then, too, it is said to induce rusting, but this again appears to be an inaccurate statement. The author considers that up to 1·5 per cent. of manganese in ingot metal is distinctly an advantage, but the percentage must not be made too great, or otherwise a fragile metal will result. With 2·7 per cent. of manganese the steel is hard and brittle, and it retains these qualities up to 7 per cent. of manganese. With still more manganese it again becomes tough and strong.

In ingot metal carbon occurs in two forms—as hardening and as

carbide carbon. Apart from the changes resulting from annealing and hardening, the conditions which lead to the larger proportion of the one form or of the other being produced are not yet completely investigated. From analyses which the author gives, he points out that the following deductions may be drawn :—(1) Under normal conditions rolling does not produce any changes in the ratio existing between the two forms of carbon ; (2) hardening-carbon exists in the greater proportion, as compared with carbide carbon, the higher the ingot metal is in carbon and manganese.

A high percentage of carbon causes the steel to possess a crystalline texture, especially in the presence of phosphorus, while manganese leads to an amorphous condition, carbon remaining in the hardening form. It follows that for good rail steels the necessary degree of hardness, that is to say, the required proportion of hardening-carbon, should not be produced by the aid of carbon, but by the use of manganese, and it is to be remembered in connection with this that manganese acts as a hardening agent apart from its binding influence on the hardening-carbon.

Oxygen, while not determined in ordinary analyses, exerts an important and objectionable influence on steel. It causes red-shortness too. Care should therefore be taken to eliminate it, whether it occurs as oxides or otherwise, as much as possible. The author next again refers to the texture of steels, and proceeds to deal with this question in considerable detail, numerous illustrations being given in connection with this portion of the subject, the work of Osmond and others being dealt with at length. He refers to and describes the different constituents observed in steel.

The next question the author considers is that of the changes produced in steel by external forces and by low temperatures. Cold makes the metal more brittle, and he considers that this shows that all those impurities which cause iron to be cold-short at ordinary temperatures exert a still greater influence as the temperature falls. Good material suffers, therefore, less than metal of a more impure kind. External forces, in addition to producing wear and deformation, may lead, as Stead has shown, to changes in the character of the material, and on this account it is best to use for rails a hard steel, and one of as homogeneous a character as possible.

The author next briefly considers the question of the hardness and toughness of rail steel. The harder material is not always the less tough. Indeed, experience has shown that mild steel rails may be

very fragile, while hard ones may prove very tough. It is now generally recognised that a texture as homogeneous as possible is the first sign by which a satisfactory rail steel may be known.

Steel and Cast Iron Water Mains.—At a meeting of the New England Waterworks Association special attention was given to the question of water mains, and several papers were devoted to the subject. Amongst other matters, the relative durability, cost, weight, &c., of steel and iron were considered. Several of the papers have appeared in abstract.*

Steel for Shipbuilding.—J. Riley † briefly traces the history of mild steel, especially in its application to the shipbuilding industry, and dwells more particularly on the effect of ferro-manganese as compared with spiegeleisen on the nature of the metal, and also with the history of testing as applied to steel. Then the effect of mild steel in ousting other materials is dealt with, especially as its cost became reduced by the improvement of methods and machinery. Statistics are given to show the increase in the production of steel and in the proportion of steel to iron ships built since 1877.

Armour-Plate Trials. Illustrations are given ‡ of a Krupp process armour-plate made by the Bethlehem Iron Company, and tested in November 1898. The plate measured 108 by 74 by $6\frac{1}{4}$ inches, and was tested with six shots, each weighing 250 to 252½ lbs., and striking velocities from 1520 to 1828 foot-seconds. The last shot at 1821 foot-seconds broke up and lodged in the backing.

Some comments have been made, in view of the recent tests of Krupp armour-plates, on their application to defeat shell-fire in war-ships.§

Some illustrations have appeared || of tested armour-plates made by Messrs. Beardmore, of Glasgow, by their special process, for the Danish Government. The plates ranged from 5·9 to 7·87 inches in thickness. The particular plate illustrated was tested with seven 112-lb. Krupp steel projectiles having a striking velocity of 1827 to 1854 foot-seconds,

* *Engineering News*, vol. xli. p. 39.

† *Engineering Magazine*, vol. xvi. pp. 175-180, 374-383. A reprint has been presented by the author to the Institute library.

‡ *Engineering*, vol. lxi. pp. 824-825.

§ *Engineer*, vol. lxxvi. p. 438.

|| *Ibid.*, p. 524.

and is considered to have borne the test very well, especially as only five shots were specified.

Illustrations have appeared * of Cammell's armour-plate, made by the Krupp process, and tested September 29 at Shoeburyness, with three Holtzer shot weighing $718\frac{1}{2}$ to $719\frac{3}{4}$ lbs. each, and fired with a striking velocity of 1846 to 1866 foot-seconds. The plate, 11·66 inches in thickness, behaved exceedingly well.

A test was made on December 2 of armour made for the Japanese battleship *Asahi*. The plate was 8 by 8 feet and 8·8 inches in thickness. Three Wheeler-Sterling projectiles, each weighing 250 lbs., were fired with striking velocities of 1859, 1964, and 2039 foot-seconds. The projectiles were shattered and the face of the plate splintered at the points of impact, but the plate was not cracked.†

J. Castner ‡ describes the trials of two armour-plates made by the Krupp process at the Carnegie Works. The plates were penetrated, but showed no cracks except slight ones at the points where the shots struck.

Recent armour-plate trials are discussed by Weyer,§ and T. A. Brassey in the "Naval Annual" gives the usual review of recent tests.

* *Engineer*, vol. lxxxvi. pp. 470-471.

† *Engineering*, vol. lxxvii. p. 47.

‡ *Stahl und Eisen*, vol. xviii. pp. 1038-1039; *Sitzungsberichte des Vereins zur Beförderung des Gewerbfleißes*, 1899, pp. 79-87.

§ *Marine Rundschau*, 1899, pp. 461-462.

CHEMICAL PROPERTIES.

Oxygen in Steel.—L. Romanoff* discusses the question of the percentage of oxygen that occurs in steel. He observes that although the presence of even small quantities of oxygen is known to possess a deleterious effect on steel, yet oxygen determinations are rarely made at works laboratories. The reason for this lies in the difficulty that exists in making oxygen determinations, complicated apparatus being required, and this is not always to be found in such laboratories. The author observes that after the rebuilding of some open-hearth furnaces, it was found that the steel was frequently burnt, and it was therefore thought desirable to make oxygen determinations in the case of the softer varieties of steel made. As a rule, 10 per cent. more air is used than is necessary theoretically to ensure the complete combustion of the gas. As in the case of the Russian furnaces in question, which are on the Vacelet system, and in which petroleum residues are used as fuel, the gas has to be burnt more rapidly, an excess of air has to be employed, and this reaches about 25 per cent. in this case. This large excess of air at first caused the steel to be burnt. Ledebur, the author observes, was the first to point out a method for the determination of oxygen in steel and its influence on the physical properties of the metal. Relatively little has since been published about this subject. The author observes that the various methods that have been proposed each present a series of difficulties of manipulation and causes of inaccuracy. He divides them into three main divisions. The first depends on the fact that dry chlorine will act on iron without acting on its oxides. A current of dry chlorine is therefore passed over the red-hot metal in a finely divided form, the iron being thus removed as a chloride. Unfortunately, however, not only do the oxides of iron remain behind, but also carbon, oxide of manganese, and a number of other compounds. The second method consists in the use of solvents

* *Stahl und Eisen*, vol. xix. pp. 265-269.

such as copper sulphate, copper chloride, iodine, bromine, &c. All these solvents possess the disadvantage that besides oxides of iron, carbon, oxide of manganese, and compounds of phosphorus and sulphur remain behind as insoluble residues. The third method consists in passing a current of dry hydrogen over the red-hot drillings. The hydrogen reduces the oxides, and the water formed is collected and weighed. The steel must, of course, be well cleaned first. If oxide of manganese is present in the steel, this forms an element of inaccuracy. Only that portion of the oxygen which is in combination with the iron is of importance, as it is this, as Ledebur has observed, that causes a deleterious effect on the metal, considering, as he does, that manganese oxide only occurs disseminated mechanically in the iron, while the iron oxide is dissolved in the metal. By combining the latter with the two other methods, very accurate results could be obtained, but such a combined method would be so complicated as to be useless from a practical point of view. Another method, proposed by Tucker, is to heat the metal with carbon in a crucible, weighing it before and afterwards, but this method the author considers liable to very grave inaccuracy. After considering all these various methods, the author concluded that only the hydrogen method of Ledebur was really of practical importance. The previous heating of the metal in a current of nitrogen appeared surrounded by difficulties, and not absolutely necessary. The author did not employ this, therefore, but his results still closely approximate to those stated by Ledebur. He first washed the steel with alcohol and ether, and then dried it in a desiccator. In some cases he did, however, employ heating in a current of nitrogen. The occurrence of hydrocarbons during the heating in hydrogen is attributed by the author not to the oil or grease introduced by the drilling operation, but to quite other causes, which he subsequently enumerates. In tabular form he states the results obtained, giving analyses of the metal, its specific gravity, rolling notes, and in two cases its relative electric conductivity, in addition to the percentage of oxygen found. This latter varied from nothing to 0.29 per cent. It would thus appear that Ledebur's statement, that this percentage of oxygen or its equivalent, 1.30 per cent. of ferrous oxide, is the maximum that can be dissolved in steel, is accurate. Further, that more than about 0.10 per cent. of oxygen is not contained in steel that will roll well; and finally, that the percentages of oxygen present in steel stand in direct connection with the specific gravities of the metal. Thus steel that rolls well, and containing as a maximum 0.11 per cent.

of oxygen, has a minimum specific gravity of 7.90, while poorer steel, with from 0.11 to 0.20 per cent. of oxygen, has a specific gravity varying from 7.90 to 7.80, and steel with over 0.20 per cent. of oxygen, which must be classed as very bad, has a specific gravity below 7.80. An increase in the percentage of oxygen from 0.15 to 0.29 per cent. caused the resistance to increase from 11.09 to 11.28 in the case of wire intended for telegraphic purposes, and containing—

| Carbon. | Phosphorus. | Manganese. | Sulphur. |
|---------|-------------|------------|----------|
| 0.25 | 0.02 | 0.55 | 0.04 |

At the same time, the specific gravity fell from 7.85 to 7.72. The first agreed with the official requirements as to conductivity, but the latter was 0.19 in excess of the standard. The author made a series of analyses at different periods during the working-off of a charge; at the same time he thus ascertained the influence exerted by the addition of ferro-manganese. The charge consisted of 2.457 metric tons of steel scrap and 0.819 ton of pig iron made by the Novorossiysk Company. The mixture was so selected as to reduce the percentages of silicon, sulphur, and phosphorus to a minimum, and thus to eliminate their influence as far as possible. A sample was taken every ten minutes. The first two samples were taken in the cold, and the others in the hot. The first addition consisted of 0.0123 ton of ferro-manganese, and a subsequent addition of twice this quantity of ferro-manganese was also made. The charge had melted down at 5 h. 50 m. in the evening, and was tapped off 1 h. 25 m. after this. During his other experiments, the author had observed that the loss in weight of the metal when heated in oxygen was greater than could be accounted for by the quantity of water formed, and this he attributes in part to the elimination of enclosed gases. The percentage of oxygen in the metal increased rapidly in the earlier stages of the process, rising from 0.14 per cent. at 5 h. 50 m. to 0.38 per cent. at 6 h. 10 m. It then fell slowly but steadily to 0.24 per cent. at 6 h. 40 m., while the first addition of ferro-manganese, at 6 h. 45 m., so diminished it that it was only 0.05 per cent. at 6 h. 50 m., and a sample taken at 7 h. 10 m., five minutes after the second addition of ferro-manganese, showed no oxygen at all. The final metal contained:—

| Carbon. | Phosphorus. | Manganese. | Sulphur. | Oxygen. |
|---------|-------------|------------|----------|---------|
| 0.085 | 0.01 | 0.37 | ... | 0.00 |

With regard to the reduction in weight when the metal is heated in a current of hydrogen, the author's experiments show that hydrocarbons

are produced. Thus a sample of pig iron showed no change in the percentage of its combined carbon after the heating in hydrogen, but its percentage of graphite had diminished from 2.90 to 2.35, and similarly in the case of mild steel the percentage of carbon fell from 0.15 to 0.11, and in hard steel from 0.43 to 0.37. The hydrocarbons which form in this way are partly volatile and partly non-volatile. This again introduces another source of error into the method.

Discussing the author's paper, A. Ledebur* observes, that more recent investigations than those to which reference is made have caused him to believe that the manganous oxide produced on the addition of ferro-manganese is not quite insoluble in iron, and that part at least remains dissolved if the metal is cast soon after the addition of the ferro-manganese. No method is as yet known by aid of which it is possible to determine the quantity of oxygen which is combined with the manganese. The chlorine method is quite useless. He considers, however, that the hydrogen method is a satisfactory one for determining the quantity of iron oxide present, and he disagrees with Romanoff's opinion that even the smallest quantity of oxygen exerts a deleterious effect on the rolling capabilities of steel, his own experiments having led him to believe that if the percentage is less than 0.1 it is without much influence on the quality of the metal, and that for rolling purposes a content of oxygen is of less influence than a similar percentage of sulphur. He doubts also the accuracy of Romanoff's conclusions as to any considerable reduction in the carbon percentage resulting from heating this metal in hydrogen.

The Condition of Silicon and Chromium in Steel.—According to A. Carnot † and Goutal, when a manganiferous ferro-silicon is subjected for a fortnight to the action of very dilute cold sulphuric acid of about 5 per cent. strength, a complex residue results, which consists chiefly of carbon, various silicides, and hydrated silica, the latter being doubtless a result of the decomposition of certain silicides. If this residue is treated with hot dilute caustic potash, the hydrated oxide and the monosilicide of iron, FeSi , are dissolved, hydroxides of iron and manganese remaining. These are dissolved in dilute sulphuric acid; the residue, washed and dried, ignited somewhat, and finally the residue is further examined with a magnet. The portion so separated is found to have the composition Fe_2Si , containing 20 per cent. of silicon and

* *Stahl und Eisen*, vol. xix. pp. 269-270.

† *Comptes Rendus de l'Académie des Sciences*, vol. cxxvi. pp. 1240-1245.
1899.—i.

80 of iron. In metal rich in manganese as well as silicon the residues contain a double silicide of iron and manganese. The following are analyses of such products :—

| | I. | II. | III. |
|-------------------|-----------|-----------|-----------|
| | Per Cent. | Per Cent. | Per Cent. |
| Iron | 68.25 | 68.60 | 71.22 |
| Manganese | 15.10 | 14.70 | 14.58 |
| Silicon | 15.40 | 15.80 | 14.00 |

The formula SiM_3 agrees with this percentage composition.

In the case of finely powdered ferro-manganese, the larger portion of which was not markedly magnetic, a magnet was found to remove about 3 per cent. of the total mass under examination. The portions so removed, when treated in the manner first described, were found to leave as a residue the silicide SiFe_2 . The authors consider, therefore, that iron products contain two silicides of iron, one having the formula FeSi and the other the formula SiFe_2 . When much manganese is also present in the iron, the metal may also contain the silicide SiM_3 , and this will contain a considerable proportion of manganese.

The authors have examined ferro-chromes containing :—

| | I. | II. |
|------------------|-----------|-----------|
| | Per Cent. | Per Cent. |
| Iron | 32.6 | 32.2 |
| Chromium | 57.6 | 59.1 |
| Carbon | 9.9 | 9.1 |

When these were treated for two days with pure hydrochloric acid, and at a temperature of 60°C ., insoluble residues were obtained. These were treated with a solution of the borate of cadmium and tungsten, and then dissolved by the aid of potassium hydrogen sulphate. The composition was found to be almost identical with that represented by the formula $\text{Fe}_3\text{Cr}_9\text{C}_7$. This might also be written $\text{Fe}_3\text{C} \cdot 3\text{Cr}_3\text{C}_2$. But Fe_3C is cementite, and Cr_3C_2 is the chromium carbide obtained by Moissan in the electric furnace. Either, therefore, the residue is a combination of these two carbides, or they exist there in admixture. In the case of steels with about 2 per cent. of chromium similar carbides were discovered, $3\text{Fe}_3\text{C} \cdot \text{Cr}_2\text{C}_3$ being met with in both cases,

although the one steel examined contained 2 per cent. of carbon and the other only 0.57 per cent. It would appear that the carbides of iron and chromium form double carbides, in which the percentage of chromium carbide varies considerably. Thus in ferro-chrome the double carbide contained three molecules of chromium carbide to one of the iron carbide, whilst in the chrome steel, poor in chromium, the double carbide contained three molecules of iron carbide to one of the chromium carbide.

A translation of the greater part of A. Abraham's important paper on nickel, chrome, and silicon steel has recently appeared.*

Arsenic in Steel.—J. Marchal† has experimented on the influence of arsenic on the mechanical properties of steel. Two small moulds, each with a capacity of 14 pounds, were filled with steel at the time of the cast from the open-hearth furnace. Into one the arsenic was introduced by means of a glass tube during the casting operation, and was absorbed and homogeneously distributed through the steel. The tests showed that the welding of steel is influenced when the arsenic amounts to 0.2 per cent., but with aid of a flux welding could be done up to 1.2 per cent. of arsenic. With more than 2.75 per cent. of arsenic the steel could not be welded, and in behaviour it resembled pig iron. As the arsenic was increased the tensile strength was developed, while the elongation decreased. It was noticed, too, that with an excessive quantity of arsenic the steel broke like pig iron. Probably this was due to the liberation of some of the combined carbon in the form of graphite. Arsenic did not affect the malleability of the steel at a red heat, and the result of the experiments has demonstrated that whereas the amount of arsenic occasionally found in steel will not affect it if otherwise pure, it will tend to increase the defects imparted by other impurities which may be present.

The Solution Theory for Iron and Steel.—B. Pawlewski‡ points out that he drew attention to the solution theory in connection with its application to iron and steel in 1893, and he believes that he was the first to do this.

* *Iron Age*, 1899, February 2, p. 6; February 9, p. 10. Compare *Journal of the Iron and Steel Institute*, 1898, No. II. p. 544.

† *Bulletin de la Société d'Encouragement*, vol. iii. pp. 1336-1340.

‡ *Chemiker Zeitung*, vol. xxiii. p. 68.

Baron H. von Jüptner * observes, that he has already endeavoured to apply the laws of solution in the case of iron and steel. He now deals generally with metallic alloys. No alloys of iron are, however, especially referred to.

Resistance of Iron to Oxidation.—Finkener † has analysed various boiler-plates and steam or hot-water pipes which had not stood well in practice. Of twelve different kinds of iron which showed very little resistance to corrosion, there was not one which was low in manganese and in phosphorus. It is best, therefore, to use for purposes of this kind a metal which contains but little of these two elements.

In a paper read by Jüngst ‡ before the Verein deutscher Eisen-giessereien, the influence of water on pipe-lines is considered at some length. Dealing in the first instance with the influence exerted by the gases contained in the water passing through them on the sides of cast iron pipes, when their use is not a constant one, he mentions the case of a pipe-line laid down in the summer of 1894. Two years later the purchaser informed the Gleiwitz Foundry, where the pipes had been cast, that in consequence of faults in the casting the pipes were bad in places, and he requested the Foundry to replace these. This was promised as soon as an inspection should show the proof of the purchaser's statements.

The pipe-line was then laid bare at about fifteen places, and throughout its whole length a very large number of the weak spots were discovered. It was, therefore, removed and replaced by one of greater thickness. The further examination of the pipes showed astonishing results. All the pipes showed faulty places. These were in the form of small holes. They were quite regular in position, and followed the direction in which the pipes ran, being always, too, at the top of the pipe, while the sides and bottom were free. It followed that faulty casting was not the cause of the failure, but that some local influences had been at work. The works, therefore, declined to substitute new pipes for the old ones without full payment. A dispute ensued, the purchaser declaring that the iron of which the pipes were made must have been unsuited to the purpose, it being admitted that the water itself was pure. Analysis showed

* *Stahl und Eisen*, vol. xix. pp. 23-28.

† *Mittheilungen aus den Königlichen technischen Versuchsanstalten zu Berlin*, vol. xv. pp. 277-278.

‡ *Stahl und Eisen*, vol. xix. pp. 133-138; two illustrations.

the percentage of manganese and phosphorus to be both high. The results were as follows :—

| Total Carbon. | Graphite. | Phosphorus. | Manganese. | Silicon. |
|---------------|-----------|-------------|------------|----------|
| 3·24 | 2·59 | 0·34 | 1·37 | 3·44 |

together with 0·03 per cent. of sulphur, 0·06 of nickel, and 0·14 of copper.

The author considers this iron quite suited for all ordinary purposes, and in proof of this he adduces the following average analyses of well-known brands :—

| | Total Carbon. | Graphite. | Phosphorus. | Manganese. | Sulphur. | Silicon. |
|------------------|---------------|-----------|-------------|------------|----------|----------|
| 1. Coltness . . | 3·50 | 3·30 | 0·98 | 1·58 | 0·02 | 3·50 |
| 2. Langloan I. . | 3·86 | 3·40 | 0·75 | 1·62 | 0·04 | 2·93 |
| 3. Clarence III. | 3·52 | 3·39 | 1·49 | 0·68 | 0·05 | 2·52 |

The author was, therefore, not prepared to admit that the iron used was unsuitable, and it lay with him to ascertain the cause of the destruction of the pipes. Analysis of the water used showed this to be of good quality. He found that the water was pumped through the pipe only at intervals, the water in the pipes being at rest for some twenty hours every day, and in motion for four hours. This led the author to believe that the destruction of the pipes must have been due to the air contained in the water, which would naturally rise to the surface when the water was at rest and oxidise the iron with which it came in contact. This view he found experimentally to be correct.

He deals next with the destructive action on iron water-pipes of the carbon dioxide contained in the water. Water from volcanic districts frequently contains large quantities of this gas, but, so far as the author knows, it has never yet been shown that the water from the New Red Sandstone contains this gas in quantities large enough to be dangerous to iron water-pipes. The town of St. Johann-on-the-Saar obtains its water from the formation, which rests upon the Saarbrücken Coal formation, and in its further extensions forms the mountains of the Palatinate and the Vosges. The water above referred to is extremely soft, and seemed very unlikely to act on the pipes through which it passed. Yet in a few years various difficulties began to be experienced. In some parts of the town the water was always coloured brown, and

was neither suited for drinking purposes nor for washing. The system of water-pipes was repeatedly washed out, but no success resulted. The pipes, too, became choked, and the author saw a connecting pipe, originally an inch wide in the clear, nearly entirely choked by such an incrustation.

The free carbon dioxide contained in the water forms in the absence of alkalies a compound with iron, which, forming a finely divided reddish-brown scum, becomes dispersed through the whole system of piping, and so leads to the difficulties in practice above referred to. The use of compressed air to expel the carbon dioxide led to a partial improvement, but the quantity of air bubbles carried forward by the water considerably reduced the efficiency of the plant. The affinity shown by the carbon dioxide for the water appears to be too great, however, to be readily overcome in this way. Analysis shows the water to contain only quite small quantities of carbonates, and it contained no dissolved mineral constituents which could lead to a rusting action on the pipes. On the other hand, the quantity of carbon dioxide amounted to about 126 cubic centimetres in every litre, a quantity which is extremely high for so soft a water, and it was to this that the rusting of the pipes was due.

J. Walter * ascribes the corrosion of rivet heads in boilers to electrolytic action.

Chemical Composition of Ingot Moulds.—O. Simmersbach † observes that the manufacture of cast iron moulds necessitates the use of as strong a cast iron as possible, one, that is, which, in addition to containing an adequate carbon percentage, is as free as possible from deleterious constituents. The following shows about the limits of chemical composition of pig iron that is suitable for moulds :—

| C. | Si. | Mn. | S. | P. | Cu. |
|------------|------------|------------|-------|-------|-------|
| 3·5 to 4·4 | 1·5 to 3·5 | 0·6 to 1·2 | 0·075 | 0·120 | 0·125 |

the three latter being maxima. Where the foundry coke used is high in sulphur, a high percentage of manganese is preferable, as some of this combines with the sulphur of the coke, and so prevents it passing into the iron. The total carbon may vary between 3·5 and 4·4 per cent., but little amorphous carbon should be present to avoid

* *Chemiker Zeitung*, vol. xxii. pp. 868-869.

† *Stahl und Eisen*, vol. xix. pp. 10-13.

the formation of a hard and brittle iron. The graphite, too, should not be in too large scales, but should be fine and evenly divided. The texture has but little influence on the character of the iron ; the grain may be fine or large, but in practice preference is generally given to a large-grained iron. Without danger to the quality of the pig iron, the above percentages of sulphur, phosphorus, and copper cannot be exceeded. Fortunately it is possible to calculate in advance exactly the percentages of phosphorus and copper which will be in the iron, as all that was in the charge will pass into it. Supervision over the slag, too, enables the iron to be kept low in sulphur, even when the ores are very sulphurous. Two such blast-furnace slags had the following composition :—

| | I. | II. |
|---------------------|-----------|-----------|
| | Per Cent. | Per Cent. |
| Iron | 1·05 | 0·99 |
| Manganese | 0·24 | 0·42 |
| Silica | 33·20 | 32·60 |
| Alumina | 12·50 | 12·18 |
| Lime | 45·80 | 47·20 |
| Magnesia | 2·95 | 4·28 |
| Sulphur | 1·53 | 1·92 |

An element which exerts a deleterious influence that is equally as intense as sulphur is arsenic. In the blast-furnace the arsenic passes to a large extent into the pig iron made, a not unimportant portion, however, passing into the slag. Thus in one case about a third of the arsenic present in the material charged passes into the slag, whilst not a trace of it could be discovered in the gases, the volatile arsenic compounds that formed having been immediately decomposed by the metallic iron. It would be best to avoid the use of arsenical ores altogether when making iron for moulds. It is, however, rare to have to deal with arsenical ores that are otherwise pure, though such ores with as much even as 1·5 per cent. of arsenic occur in the South of Spain. When, however, ores have to be treated which contain small quantities of arsenic, it is well to make the permissible maximum for sulphur and arsenic taken together 0·075, as previously stated for sulphur alone. The way in which the pig iron to be used for moulds is treated in the cupola is of the greatest importance. The remelting of such a special iron requires much more experience, care, and skill than when ordinary pig iron is being dealt with. The iron has to be

kept as pure as it was originally. The following composition of the metal forming the ingot mould may be taken as typical :—

| C. | Si. | Mn. | S. | P. | Cu. |
|------------|------------|------------|-------|-------|-------|
| 3.3 to 4.4 | 1.6 to 3.0 | 0.5 to 1.1 | 0.075 | 0.125 | 0.125 |

the three latter again being maxima. Within the above limits, the silicon exerts no influence on the life of the mould. Moulds with 1.6 per cent. of silicon have lasted just as long as others with 2.8 per cent. This indifference of behaviour relates, however, only to the silicon that was derived from the original charge. Any silicon, on the other hand, that passes into the iron from the fuel or furnace lining by increasing the separation of graphite is indirectly dangerous in its action. Thus if the iron is overheated in the cupola, with the result that it remains longer in contact with the furnace walls and the slag, it takes up a good deal of silicon, with the result that more graphite separates out, and this is not regularly disseminated, with the result that these irregular segregations weaken the iron. In practice it is not uncommon to find that moulds with about $2\frac{1}{4}$ per cent. of silicon will last only twenty casts, while others with a higher percentage will last a hundred. The cause is then to be sought in the overheating of the metal in the cupola. This can always be detected, as in that case the moulds will be higher in silicon than the original metal before remelting. It is evident, therefore, how important is the right temperature and fusion period in the cupola.

The influence exerted by the sulphur makes itself much more strongly felt than does that of the silicon. In foundries the determination of the sulphur in the coke used is still often left undone, although the percentage present varies greatly. In the Dortmund district the percentage of sulphur in coke averages about 1.1, while in Upper Silesia the local coke contains from 0.7 to over 2 per cent.; Waldenburg coke may contain about 1.8 per cent. of sulphur, and the Ostrau coke averages 1.4 per cent. When all these different varieties of coke are in use, the determination of the sulphur is not only desirable occasionally, but is absolutely necessary. To prevent the sulphur in the coke from being dangerous, apart from the use of high manganese iron, the slag must be made very basic. If this is not done the sulphur will pass partly into the iron. An increase in the percentage of sulphur in the iron during the remelting causes the carbon in the mould to be present more in the amorphous form, as well as inducing a lower percentage of total carbon,

despite the fact that in the cupola more carbon is usually taken up by the iron from the coke used, steel even passing into pig iron in this way. Thus in one case from a pig iron to be used for moulds which contained 0·05 per cent. of sulphur and about 4 per cent. of carbon, there resulted after remelting in the cupola, in consequence of the percentage of sulphur in the coke used having been neglected, a mould the metal of which contained 0·27 per cent. of sulphur and only 2·8 per cent. of carbon—a metal which was quite useless for this purpose. If the metal of a mould shows more than 0·1 of sulphur, it is no longer among the most suitable, and will not last long, while, if it reaches or exceeds 1·5 per cent., the metal becomes red-short, and the hot mould cracks and falls in pieces. The following are analyses of the metal of such unsatisfactory moulds:—

| | I. | II. | III. | IV. |
|--------------------|-----------|-----------|-----------|-----------|
| | Per Cent. | Per Cent. | Per Cent. | Per Cent. |
| Silicon | 2·140 | 2·290 | 2·280 | 2·070 |
| Manganese | 0·420 | 0·530 | 0·750 | 0·380 |
| Phosphorus | 0·108 | 0·100 | 0·063 | 0·150 |
| Sulphur | 0·135 | 0·180 | 0·200 | 0·150 |

Two parts of sulphur exert more action on the iron than 25 parts of other constituents.

Phosphorus is similar in its action to sulphur, only to a lesser extent. Moulds with less than 0·125 per cent. of phosphorus give no cause of complaint if other impurities are absent. When the percentage of phosphorus reaches 0·18, the metal can no longer be considered of the best quality. Thus moulds having the following compositions behaved badly in use:—

| | I. | II. |
|--------------------|----------------|----------------|
| | Per Cent. | Per Cent. |
| Silicon | 2·370 | Not determined |
| Manganese | 0·450 | 0·880 |
| Phosphorus | 0·217 | 0·187 |
| Sulphur | 0·066 | 0·065 |
| Carbon | Not determined | 3·660 |

The high phosphorus is usually due to the original pig iron, or to the addition in the cupola, although if a coke is used that is high in phos-

phorus an increase due to this cause will take place, all the phosphorus in the coke always passing into the iron. In Upper Silesia cokes are sometimes used that contain as much as 0.09 per cent. of phosphorus.

Copper is somewhat similar in its action to phosphorus. If the percentage does not exceed 0.125, then it is without influence on the mould, provided the percentage of sulphur is normal. It is well, however, to avoid higher percentages, especially in view of the fact that the copper tends to cause a retention of the sulphur. The copper in the mould comes only from the iron used, too little copper occurring in the coke to admit of the percentage present in the mould being at all noticeably affected in this way.

With regard to the influence of manganese, the presence of more than 1 per cent. in the mould is often looked upon as dangerous, but this view appears to be absolutely wrong. A mould, the author observes, with 1 per cent. of manganese will last longer than another with only 0.5 per cent. if the percentage of sulphur is about 0.09, as the manganese tends to prevent the sulphur making the metal of the mould red-short. Manganese, too, acts on the state of the carbon in the iron, hindering the formation of amorphous carbon. The following are analyses of moulds that lasted well in practice, No. I. having indeed stood almost 250 casts:—

| | I. | II. | III. | IV. |
|------------------|-----------|-----------|-----------|-----------|
| | Per Cent. | Per Cent. | Per Cent. | Per Cent. |
| Silicon . . . | 2.650 | 1.660 | 2.800 | 2.160 |
| Manganese . . . | 1.000 | 0.550 | 0.830 | 0.730 |
| Phosphorus . . . | 0.064 | 0.054 | 0.120 | 0.060 |
| Sulphur . . . | 0.061 | 0.043 | 0.040 | 0.050 |
| Copper . . . | ... | 0.072 | 0.065 | 0.120 |
| Carbon . . . | ... | 3.450 | 4.400 | ... |

The very varying views which are held in practice as to the right composition for moulds are due to the fact that the simultaneous influences exerted by all the different constituents of the metal are not sufficiently regarded. Moulds have to stand repeated heatings and coolings, and consequently much care should be devoted in their manufacture, as well as proper treatment in practice. These points he considers, and he also refers to the thicknesses to be given to the sides, observing that in the United Kingdom they are usually kept thicker than in Germany. He points out that if moulds are cooled irregularly, even the best will only stand a few casts.

A. Zugger * states that the ingot moulds made at an Austrian works, which are well known for their excellent lasting qualities, have the following analytical composition :—

| Graphite. | Combined Carbon. | Silicon. | Manganese. | Phosphorus. | Sulphur. |
|-----------|------------------|----------|------------|-------------|----------|
| 3.293 | 0.577 | 1.27 | 1.29 | 0.147 | 0.061 |

The low percentage of silicon is noticeable. These moulds, the author states, last from 200 to 300 casts. The metal from which the moulds are made is charcoal iron. The shape of the moulds, the author observes, has an important bearing on their durability. For similar pig iron moulds approximately square in cross-section last the best. It is best, too, to use for the moulds a somewhat fine-grained iron, not too graphitic, as this is not subject to such rapid corrosion.

Composition of Armour-Plates.—Captain O'Neil, † in an official statement in the United States, has given the following composition for Krupp armour-plates :—

| Not less than | | | | Not more than | | | |
|---------------|-----|-----|-----|---------------|------|------|--------------|
| Ni. | Cr. | C. | Mn. | Cu. | P. | S. | Si. |
| 3.5 | 1.3 | 0.2 | 0.4 | 0.07 | 0.03 | 0.03 | 0.05 to 0.15 |

* *Stahl und Eisen*, vol. xix. pp. 77.

† *Iron Age*, March 2, 1899, p. 18.

CHEMICAL ANALYSIS.

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I.—ANALYSIS OF IRON AND STEEL.

Quantitative Metallurgical Analysis.—The adoption of tables for the purpose of facilitating qualitative chemical analysis has long been a familiar device, and J. J. Morgan * has now published a work dealing with quantitative analysis, in which the system of tabulated directions is solely employed. By such tables the work of the chemist is lightened owing to the time saved in not having to hunt through the pages of superfluous detail so often found in larger works. The author's tables deal chiefly with the analysis of iron and steel, iron ores, limestone, firebricks, blast-furnace slag, fuel, water for technical purposes, gaseous fuels, and chimney-gas.

Determination of Carbon.—A. Girard † recommends the copper-ammonium chloride method for the determination of carbon, especially in the case of ferro-chrome or ferro-silicon, as these substances are only with difficulty decomposed completely by sulphuric-chromic acid. The method as arranged by Campredon gives good results. In this from 10 to 15 cubic centimetres of hydrochloric acid is employed with the double chloride in weight equal to ten times the weight of the metal to be analysed, together with from 100 to 200 cubic centimetres of water. A blind check analysis is always necessary, especially when the Wiborgh apparatus is used, as this does not give very accurate results.

* "Tables for Quantitative Metallurgical Analysis for Laboratory Use." London: Charles Griffin & Co., Limited, 1899.

† *Zeitschrift für angewandte Chemie*, 1898, p. 265.

Determination of Manganese.—F. W. Daw* regards the presence of organic matter, the reckless use of zinc oxide in large quantities, and the standardising of the permanganate with iron instead of manganese, as sources of error in the estimation of manganese by means of permanganate, and describes a method in which these errors are eliminated. Incidentally in the analysis of the standard ferro-manganese he ignites the trimanganic tetroxide over a blow-pipe in a platinum crucible, and in answer to remarks by H. Brearley† on the probable effect of the permeability of heated platinum to gases on the result, he quotes some very concordant results obtained over the blow-pipe, as compared with unsatisfactory ones obtained in a muffle unless it is very hot. If iron is used to standardise the permanganate, a figure is obtained which gives low results when working on manganese, and is attributed to want of knowledge of the actual reaction that does take place. Brearley is inclined to credit the carbon in the iron as having some influence; but this Daw does not admit.

Determination of Tungsten.—The rapid method of determining tungsten in steel, generally in use and described in Blair's "Chemical Analysis of Iron," is as follows:—Solution of the steel in aqua regia; evaporation to dryness; re-solution in strong hydrofluoric acid containing a little strong nitric acid; dilution and boiling: filtration and ignition of the tungstic oxide contaminated with silica and ferric oxide; elimination of the silica by hydrofluoric acid; ignition, and weighing of the tungstic acid and ferric oxide; fusion with sodium carbonate; solution and filtration to determine the ferric oxide. If in this method the final steps—the fusion with sodium carbonate and the determination of the ferric oxide—could be dispensed with, evidently a very considerable saving of time and trouble in the performance of the method would be made; and it has been observed that the ferric oxide thus carried down with the tungstic acid is constant in amount, or nearly so. If this uniformity exists in all steels containing every percentage of tungsten, of course the determination of this ferric oxide contamination in every particular instance is unnecessary. G. Auchy‡ suggests that if works-chemists having to do with tungsten in steel would gather from their note-books and publish the data representing the amounts of ferric oxide found

* *Chemical News*, vol. lxxix. pp. 25, 58, 104.

† *Ibid.*, pp. 47, 83-84.

‡ *Journal of the American Chemical Society*, vol. xxi. pp. 239-245.

contaminating their tungstic acid precipitates, the uniformity of these ferric oxide contaminations would no doubt be shown and result in the improvement of the method. His own experience is confined to steels containing 0.20 per cent. to 1.75 per cent. tungsten, and indicates that the ferric oxide contamination is always practically the same within those limits, and that the amount, with four grammes steel taken for analysis and with varying amounts of acid present in solution, is about 0.03 per cent. in terms of tungsten.

Determination of Tin in Tin-Plate.—According to R. Job,* in a 200 cubic centimetre flask, about 100 cubic centimetres of pure hydrochloric acid of specific gravity 1.2 is placed, a piece of marble weighing about five grammes is dropped in, and the flask is closed with a perforated cork fitted with a Bunsen valve. After about five minutes, 4 square inches of the tin-plate from the middle of a sheet, cut into strips, is dropped into the acid, and the flask is heated until the action becomes vigorous. When the plate is nearly dissolved, another fragment of marble is added, and immediately the plate is entirely dissolved, and while effervescence from the marble still continues, the flask is cooled as rapidly as possible to 0°. It is then filled to the mark with ice-cold water, the contents mixed, and 50 cubic centimetres of the solution titrated with iodine (1 cubic centimetre = 0.00056 gramme of tin). A fresh quantity of the iodine solution, equal to that required in the first titration, is then placed in a flask, and 50 cubic centimetres of the tin solution delivered into it, keeping the point of the pipette just below the surface; in this way oxidation by air is completely avoided. A little starch is added and the titration finished with the iodine.

Laboratory Furnace.—Illustrations have appeared† of a new gas-fired laboratory furnace devised by G. T. Holloway. The body and base are made separate to avoid cracking.

Atomic Weights.—The committee appointed by the German Chemical Society, consisting of Landolt, Ostwald, and Seubert, to determine the values of the atomic weights that should be employed for purposes of analysis or assaying, recommend that the atomic weight of oxygen should be taken as 16.00, and on this basis the values of

* *Journal of the Society of Chemical Industry*, vol. xvii. pp. 325-326.

† *Colliery Guardian*, vol. lxxvi. p. 1126.

the atomic weights of other elements should be calculated. The following values, which are probably the most correct yet obtained, should be adopted for the elements usually dealt with in metallurgical practice :—

| | | | |
|---------------------|--------|----------------------|--------|
| Aluminium | 27.1 | Manganese | 55.0 |
| Antimony | 120.0 | Mercury | 200.3 |
| Arsenic | 75.0 | Molybdenum | 96.0 |
| Barium | 137.4 | Nickel | 58.7 |
| Bismuth | 208.5 | Nitrogen | 14.04 |
| Boron | 11.0 | Oxygen | 16.0 |
| Bromine | 79.9 | Phosphorus | 31.0 |
| Calcium | 40.0 | Platinum | 194.8 |
| Carbon | 12.0 | Potassium | 39.15 |
| Chlorine | 35.45 | Silicon | 28.4 |
| Chromium | 52.1 | Silver | 107.93 |
| Cobalt | 59.0 | Sodium | 23.05 |
| Copper | 63.6 | Strontium | 87.6 |
| Fluorine | 19.0 | Sulphur | 32.06 |
| Gold | 197.2 | Tin | 118.5 |
| Hydrogen | 1.01 | Titanium | 48.1 |
| Iodine | 126.85 | Tungsten | 184.0 |
| Iron | 56.0 | Vanadium | 51.2 |
| Lead | 206.9 | Zinc | 65.4 |
| Magnesium | 24.36 | | |

II.—ANALYSIS OF IRON ORES.

Volumetric Methods of Analysis.—J. Wagner * notes a number of difficulties in connection with titration by the aid of potassium permanganate. Thus, among other points, he observes that with the presence of barium chloride in the solution titrated a large excess of permanganate is used. This may even amount to as much as 45 per cent. Secondary reactions, he shows, are of frequent occurrence.

Sodium hyposulphite solution can only be standardised by the aid of potassium bichromate under special conditions, as more iodine is apt to be separated than corresponds with the quantity of bichromate employed. It induces greater action between the oxygen of the air and the hydroiodic acid.

The Electrolytic Determination of Iron.—S. Avery and B. Dales † have made careful estimations of iron by the usual electro-

* *Stahl und Eisen*, vol. xix. p. 283.

† *Berichte der deutschen chemischen Gesellschaft*, vol. xxxii. pp. 65-68; *Journal of the Chemical Society*, vol. lxxvi. pp. 251-252.

lytic methods, and have found that in all cases a certain amount of carbon is deposited together with the iron. When the estimation is carried out in ammonium oxalate solution, some 0.22 per cent. of the deposit consists of carbon, and a small quantity of iron still remains in solution. In citric acid solution as much as 2 per cent. of the deposit often consists of carbon. When Moore's method of depositing the iron from ammonium metaphosphate solution is employed, some 2 per cent. of carbon and phosphorus is also deposited.

Analysis of Swedish Magnetic Iron Ores.—According to T. Wetzke,* the solution in hydrochloric acid is effected by micro-burners so as to avoid boiling, and the vessel is covered; the iron is finally titrated with permanganate, any sulphurous insoluble residue being examined by Hauffe's method. Phosphorus is best estimated by the process recommended by Meineke, namely, ignition of the phospho-molybdate precipitate in a Gooch crucible.

Valuation of Iron and Manganese Ores.—According to Paul Lehnkering† the quick processes of analysing iron and manganese ores usually employed are not trustworthy if the ores contain organic matter, or insoluble ferruginous silicates, or sulphides. The presence of titanium, arsenic, or copper compounds also interferes.

The following process is recommended by the author in the case of reference analyses. Five grains of the finely powdered and dried ore, after being ignited in a porcelain crucible for half an hour over a Bunsen flame to destroy any organic matter, is heated in an Erlenmeyer flask with 60 cubic centimetres of hydrochloric acid of specific gravity = 1.19, on the water-bath for four hours, evaporated to dryness, the residue dissolved in hydrochloric acid, 100 cubic centimetres of hot water added, and the insoluble matter washed with hot dilute hydrochloric acid. The residue is then dried and fused in a platinum crucible with 5 grammes of sodium potassium carbonate and a little nitre, and when cold the fused mass is dissolved in hydrochloric acid, and the solution evaporated with the addition of sulphuric acid. The residue, dissolved in dilute hydrochloric acid, is filtered, and the iron in the filtrate precipitated by ammonia, washed, redissolved in dilute hydrochloric acid, and the solution added to the main liquid. Any

* *Zeitschrift für öffentliche Chemie*, vol. iii. pp. 575-577.

† *Ibid.*, vol. iv. pp. 459-464; *Journal of the Chemical Society*, vol. lxxvi. p. 251.

arsenic or copper is now precipitated by hydrogen sulphide, the excess of the latter being removed by boiling and treating with potassium chlorate. After boiling off the chlorine, the iron is titrated, preferably by the stannous chloride permanganate method.

For the estimation of manganese in ores, the author does not recommend the volumetric processes, but prefers estimating the metal as sulphide. The ore is first dried at 120° , and any matter insoluble in hydrochloric acid must always be fused with sodium potassium carbonate to recover any insoluble manganese.

Silica obtained from iron or manganese ores may be contaminated with insoluble sulphates or titanous acid; the latter may be separated by fusing with potassium hydrogen sulphate and extracting the fused mass with cold water. The mixture of silica and insoluble sulphates is then weighed and heated with sulphuric and hydrofluoric acids. The loss represents silica.

III.—GAS ANALYSIS.

New Gas Analysis Apparatus. — E. Hankus* describes a modified form of the Orsat apparatus for gas analysis. His modified apparatus, the author observes, is useful not only for colliery purposes, but also for the analysis of blast-furnace gases. In the author's apparatus not only may carbon dioxide, carbon monoxide, oxygen and marsh-gas be determined, but also hydrogen and hydrocarbons C_nH_{2n} . In addition he has modified the system of gas absorption bottles in such a way as to ensure a more rapid rate of absorption, especially of carbon monoxide. In addition to the bottles of the ordinary Orsat apparatus there is a combustion vessel and tubes filled with palladium sponge.

In using the apparatus the carbon dioxide is first absorbed by means of caustic potash. In the second vessel the heavy hydrocarbons C_nH_{2n} and those of the benzol series C_nH_{2n-6} are absorbed by highly concentrated fuming sulphuric acid, which at $0^{\circ}C$. yields crystals of pyrosulphuric acid. Less concentrated acid gives unsatisfactory results, the absorption being then very incomplete. The absorption is always very slow even with the concentrated acid. After it is ended the vapours are passed into a vessel containing

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlvii. pp. 81-83; three illustrations.

caustic potash. In the next vessel the oxygen is absorbed by potassium pyrogallate, and in the next the carbon monoxide by an ammoniacal solution of cuprous chloride. All apparatus of this type gives somewhat unsatisfactory results as regards carbon monoxide, its absorption by the copper salt used never appearing to be perfectly complete. After absorption in cuprous chloride the gas is passed into caustic potash before reading off, to condense any ammonia it may contain. Next comes a tube containing palladium sponge for the oxidation of the hydrogen. This palladium sponge is in quantity from 0·5 gramme to 1 gramme. It is not pure, but is mixed with asbestos. The method of calculating the percentage of hydrogen from the results observed is described. The residual gas is then passed into the combustion vessel for the determination of the marsh-gas. In this it is burnt by the aid of a palladium spiral raised to redness by a current of electricity. The method of calculation is again described. After deducting all these various constituents the remaining gas will represent the percentage of nitrogen originally present.

J. Teichner* discusses the use of the Jeller apparatus† for the determination of small quantities of marsh-gas and carbon dioxide in the air escaping from collieries. He mentions various difficulties that are experienced with this apparatus and shows how these may be obviated.

An account is published by Von Knorre‡ of Shaw's apparatus§ for testing gases.

E. H. Earnshaw|| discusses the composition and analysis of water-gas.

H. Le Chatelier¶ has devised an apparatus for the rapid testing of flue gases from furnaces. For the control of the stoking it is merely necessary to ascertain whether oxygen or carbonic oxide is in excess in the gases. This is most conveniently done with the aid of copper, heated sufficiently to initiate oxidation or reduction as the case may be.

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlv. p. 691; one illustration.

† *Journal of the Iron and Steel Institute*, 1898, No. II. p. 565.

‡ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlv. pp. 730-732; one illustration.

§ *Journal of the Iron and Steel Institute*, 1898, No. II. p. 565.

|| *Journal of the Franklin Institute*, vol. cxlvi. pp. 161-176, 303-307.

¶ *Bulletin de la Société d'Encouragement*, vol. iv. pp. 113-116.

STATISTICS.

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I.—UNITED KINGDOM.

Mineral Statistics.—According to the official statistics of H.M. Inspectors of Mines,* the total number of persons employed in about all the mines of the United Kingdom during the year 1898 was 741,125, of whom 706,894 worked at the 3249 mines under the Coal Mines Act, and 34,231 at the 752 mines under the Metalliferous Mines Act. Compared with 1897 there is an increase of 11,681 persons at mines under the Coal Mines Act, and an increase of 731 persons at the mines under the Metalliferous Mines Act. Of the 706,894 persons working at mines under the Coal Mines Act, 567,124, or about 80 per cent., were employed below ground. Of the 139,700 surface workers, 4617, or 3·3 per cent., were females. At the mines under the Metalliferous Mines Act, 20,173 persons, or nearly 59 per cent., worked below ground, and of the 14,058 surface workers, 509, or 3·6 per cent., were females. The total output of minerals at mines under the Coal Mines

* *Mines and Quarries: General Report and Statistics for 1898.* Part 1., District Statistics. London, 1899.

Act was 215,161,954 tons, of which 202,042,243 were coal, 2,783,219 fireclay, 7,901,046 ironstone, 2,137,993 oil-shale, and 297,453 sundry minerals. Adding 12,273 tons from open quarries, the total output of coal was 202,054,516 tons, which is lower than that of the previous year by 75,415 tons.

At the mines under the Coal Mines Act there were 828 separate fatal accidents, causing 908 deaths. Compared with 1897, there is a decrease of 40 in the number of accidents, and a decrease of 22 in the number of deaths. At the mines under the Metalliferous Mines Act there were 31 fatal accidents, which caused 33 deaths. Compared with 1897, there is an increase of 2 in the number of accidents and a decrease of 16 in the number of deaths.

Iron Trade Statistics.—The British Iron Trade Association reports * the production of iron and steel in the United Kingdom in 1898 to have been as follows :—

| | Tons. |
|--|-----------|
| Total pig iron | 8,631,151 |
| Wrought iron | 1,115,699 |
| Bessemer steel ingots, | 1,759,386 |
| " " acid | 1,255,252 |
| " " basic | 504,134 |
| " " rails | 751,591 |
| Open-hearth steel ingots, acid | 2,590,512 |
| " " basic | 216,088 |
| " " total | 2,806,600 |

There were in operation 297 blast-furnaces, 1658 puddling-furnaces, 42 acid Bessemer converters, 20 basic Bessemer converters, 273 acid open-hearth furnaces and 34 basic open-hearth furnaces.

Blast-Furnace Statistics.—The following is a summary of the position of furnaces built and in blast on December 31, 1898, compiled from returns received direct from the furnaces : †—

| | |
|--|-----|
| Total number of furnaces built on December 31, 1898 . . . | 632 |
| Total number of furnaces in blast on December 31, 1898 . . | 399 |
| Increase in the number of furnaces built since September 30, 1898 | 1 |
| Increase in the number of furnaces in blast since September 30, 1898 | 13 |

* *Iron and Coal Trades Review*, vol. lviii. pp. 385, 429, 473, 605.

† *Iron Trade Circular* (Rylands), Supplement, January 14, 1899, p. 25.

Imports and Exports.—According to the Board of Trade returns, the exports from the United Kingdom during 1898 were as follows :—

| | Tons. |
|---------------------------------------|-----------|
| Pig iron | 1,042,296 |
| Hoops, sheets, and plates | 101,022 |
| Bar, angle, bolt, and rod | 150,503 |
| Railroad iron | 610,213 |
| Wire | 44,246 |
| Tin-plates | 251,769 |
| Cast and wrought | 356,227 |
| Old iron | ... |
| Unwrought steel | 285,612 |
| Steel and iron manufactures | 35,292 |

The imports were as follows :—

| | Tons. |
|---------------------------------------|----------------|
| Iron ores | 5,468,395 |
| Bar, angle, bolt, and rod | 69,224 |
| Unwrought steel | 40,231 |
| Girders, beams, and pillars | 103,439 |
| Unenumerated | 216,863 |
| | <u>429,757</u> |

The Coal Question.—T. Forster Brown * discusses the problem of our coal supplies in this country, and concludes that the total supplies at the present and prospective rate of output will last probably three centuries, but the cheapest will only last half a century. That if we do not during that period of fifty years provide in some way to meet the gradually but steadily increasing cost of our coal, after fifty years, owing to natural causes, we shall be unable to compete successfully with America and the East, and it must follow that our commercial supremacy will disappear ; whilst it is suggested that if the capital value of our railways and other works were paid off in these fifty years, and the cost of travelling and transit of minerals reduced by one-half, the increased cost of our coal, due to natural causes, would be practically neutralised, and the nation would be able to hold its own so long, at all events, as the coal resources of the country endured.

R. Schneider † compares the coal industry of the United Kingdom with that of other countries, especially the United States and Germany. In 1840, and in 1895, the percentage of the total world's output mined in these three countries was as follows :—

* *Journal of the Society of Arts*, vol. xlvii. pp. 506-517.

† *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlvi. pp. 742-743.

| | United Kingdom. | United States. | Germany. |
|--------------|-----------------|----------------|-----------|
| | Per Cent. | Per Cent. | Per Cent. |
| 1840 | 75·0 | 4·0 | 5·5 |
| 1895 | 33·8 | 31·0 | 18·0 |

The author points out that the output of coal in the United Kingdom in 1839 was only 31,000,000 tons, and that in 1897 it amounted to 205,369,000 tons, and he asks the question as to how long the coal resources of the country will last. Even in 1930 he considers there will be 182,000 million tons left, and that consequently it will be many centuries before the coalfields are exhausted.

II.—AUSTRALASIA

Coal-Mining in Queensland.—According to the Annual Report of the Under Secretary for Mines for the year 1897 the output of coal was 358,407 tons. The quantity exported was 7369 tons, and that imported 21,282 tons.

Coal-Mining in Tasmania.—According to the Report of the Secretary of Mines, the output of coal in Tasmania during the financial year 1897–98 was 48,501 tons.

III.—AUSTRIA-HUNGARY.

Iron Trade Statistics of Austria.—The production in Austria in 1897 included : *—

| Material. | in 1897. | with 1896. |
|----------------------------|--------------|--------------|
| | Metric Tons. | Metric Tons. |
| Iron ore | 1,613,876 | 165,261 |
| Manganese ore | 6,012 | 2,061 |
| Coal | 10,492,771 | 593,249 |
| Brown coal | 20,458,093 | 1,575,556 |
| Forge pig iron | 762,685 | 69,496 |
| Foundry pig iron | 125,260 | 1,481 |

In addition, 38,504 tons of graphite and 300 tons of asphalt rock were also produced, together with small quantities of both nickeliferous and

* *Statistisches Jahrbuch des k.k. Ackerbauministeriums für 1897*, Part II.; *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlv. pp. 667–668, 678–682, 695–698.

cobaltiferous products and 31 tons of wolfram. The production of iron ore and pig iron was as follows in the different divisions of the Empire :—

| Division. | Iron Ore. | Forge Pig Iron. | Foundry Pig Iron. | Proportion of Total Pig Iron Production. |
|-------------------------|--------------|-----------------|-------------------|--|
| | Metric Tons. | Metric Tons. | Metric Tons. | Per Cent. |
| Bohemia | 594,011 | 211,699 | 13,120 | 25·32 |
| Lower Austria | 1,340 | 47,086 | 11,593 | 6·61 |
| Upper Austria | ... | ... | ... | ... |
| Salzburg | 7,627 | ... | 2,137 | 0·24 |
| Moravia | 5,618 | 209,274 | 74,888 | 32·00 |
| Silesia | ... | 36,975 | 16,828 | 6·06 |
| Bukowina | ... | ... | ... | ... |
| Styria | 928,446 | 220,408 | 2,208 | 25·07 |
| Carinthia | 62,502 | 27,592 | 1,588 | 3·29 |
| Tyrol | 6,593 | 677 | 1,052 | 0·19 |
| Carniola | 5,033 | 4,906 | ... | 0·55 |
| Trieste | ... | 4,068 | ... | 0·46 |
| Galicia | 2,705 | ... | 1,847 | 0·21 |
| Totals | 1,613,876 | 762,685 | 125,261 | 100·00 |

These figures show increase in the production of pig iron in seven divisions, and diminution in the out-turn in four.

In the iron ore mines 5269 workpeople were employed, this being an increase of 400 as compared with the previous year, and in the ironworks 6646, an increase of 366. The total blast-furnaces numbered 89, a diminution of 2. Of these, 55 were in blast for 2377 weeks, or 3 furnaces and 86 weeks less than in the preceding year. Details are given as to the average prices for which the ore and pig iron sold in the several divisions of the Empire.

The production of coal and brown coal was as follows :—

| Division. | Coal. | Proportion of Total Output. | Brown Coal. | Proportion of Total Output. |
|-------------------------|--------------|-----------------------------|--------------|-----------------------------|
| | Metric Tons. | Per Cent. | Metric Tons. | Per Cent. |
| Bohemia | 4,033,276 | 38·44 | 16,921,052 | 82·71 |
| Lower Austria | 48,254 | 0·46 | 2,286 | 0·01 |
| Upper Austria | ... | ... | 387,878 | 1·90 |
| Moravia | 1,419,359 | 13·53 | 151,811 | 0·74 |
| Silesia | 4,190,924 | 39·94 | 1,008 | 0·00 |
| Styria | 205 | 0·00 | 2,446,306 | 11·96 |
| Galicia | 800,752 | ·63 | 60,714 | 0·30 |
| Carinthia | ... | ... | 83,247 | 0·41 |
| Tyrol | ... | ... | 24,508 | 0·12 |
| Carniola | ... | ... | 235,612 | 1·15 |
| (Görz and) | ... | ... | 750 | 0·00 |
| Gradiska) | ... | ... | ... | ... |
| Dalmatia | ... | ... | 72,079 | 0·35 |
| Istria | ... | ... | 70,840 | 0·35 |

The exports of brown coal amounted to 8,423,463, and 30,585 tons of brown coal briquettes were also exported. These totals show increases respectively of 14·29 per cent. and 7·47 per cent. as compared with the corresponding figures for the previous year.

The quantity of coal coked was 1,457,299 tons, and from this 926,309 tons of coke were produced, the percentage yield being thus about 63·56. The briquettes made amounted to 23,721 tons. The by-products from the coke-ovens included 201·7 tons of ammoniacal water, 1548 tons of ammonium sulphate, 4573 tons of tar, 405 tons of pitch, 153 tons of asphaltic material, 2 tons of tar oil, and a variety of other substances, the quantities for which are also given.

The coal and coke exported amounted respectively to 1,202,658 tons and 217,703 tons, most of this going to Hungary and Germany. The number of workpeople employed at the collieries was 58,067, or 2141 more than in 1896. The total value of all the minerals raised in Austria in 1897 was 137,914,865 florins, say £11,500,000, and the total number of workpeople employed 141,445, these figures being in excess of the corresponding ones of the previous year by 13,249,341 florins, approximating £1,100,000, and 5528 in the number of the workpeople.

Hungarian Mineral Statistics.—The following statistics show the production in Hungary in 1897 of the materials mentioned : *—

| | Metric Tons. |
|----------------------|--------------|
| Brown coal | 3,870,530 |
| Coal | 1,118,025 |
| Briquettes | 27,022 |
| Iron ore | 1,421,129 |

There was exported from Hungary in 1897, 3976 tons of manganese ore, 19,000 tons of raw asphalt rock, 3057 tons of asphalt, 2168 tons of petroleum, and 471,420 tons of iron ore.

The mineral statistics for Hungary for the year 1897 † show that of the surface area devoted to mining, 58·3 per cent. relates to coal-mining and 17·6 per cent. to iron ore mining. Full statistical details are given as to the length of railways, number and kind of pumping and winding appliances, fans, &c., at the various mines. At the iron ore mines 58 electric rock drills are in use, 51 of these being in the Szepes-Igló mining district. There are 172 coke-ovens. The smelting

* *Ungarisches Statistisches Jahrbuch*, vol. v.

† *Bányászati és kohászati lapok*, 1898; *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlvii. pp. 19-21, 35-36.

works possessed 69 blast-furnaces in 1897, as compared with 63 in 1896. Full details are given as to the other kinds of furnaces in use at the various other smelting works.

The total number of workpeople employed in coal and brown coal mining in Hungary in 1897 was 28,326, and in iron ore mining 10,181.* As compared with the similar statistics for the previous year, the former number shows an increase of 3·5 per cent., and the latter of 2·8 per cent. Of the above total of workpeople employed in coal and brown coal mining, 33·2 per cent. were engaged at coal-mines and 66·8 at brown coal mines. The average daily wage earned by a miner in Hungary in 1897 varied from 0·3 florin to 3·2 florins, a slight diminution as compared with the previous year. The total number of workpeople employed in smelting works in Hungary in 1897 numbered 8874, as compared with 8784 in 1896.

The accidents in Hungarian mines in 1897 are shown in the following table : +—

| | Accidents. | | | Workpeople Employed. |
|-----------------------------|------------|---------|--------|----------------------|
| | Fatal. | Severe. | Total. | |
| Coal-mining | 16 | 39 | 55 | 9,414 |
| Brown coal mining | 39 | 69 | 108 | 18,912 |
| Iron ore mining | 14 | 37 | 51 | 10,181 |
| Other mining | 9 | 27 | 36 | 17,982 |
| Totals | | 172 | 250 | 56,489 |

Brown Coal in Bohemia.—According to the official statistics, the production of brown coal in Bohemia in 1898 was as follows :—

| District. | Output in Tons. | Miners. Employed. |
|-------------------|-----------------|-------------------|
| Brüx | 11,411,484 | 18,621 |
| Komotau | 836,894 | 1,522 |
| Teplitz | 2,796,185 | 5,069 |
| Totals | 15,044,563 | 25,212 |

The production is 2 per cent. greater than that of 1897 and 13 per cent. greater than that of 1896.

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlvii. p. 75.

+ *Ibid.*, p. 86.

Consumption of Fuel.—F. Kupelwieser* estimates that the production and consumption of fuel in Austria-Hungary in 1896 was as follows:—

| <i>Austria.</i> | | Tons. |
|------------------------------|--|------------|
| Lignite production | | 18,882,537 |
| „ consumption | | 11,279,585 |
| Coal production | | 9,899,522 |
| „ consumption | | 13,149,075 |
| Coke production | | 821,535 |
| „ consumption | | 951,144 |
| <i>Hungary.</i> | | |
| Lignite production | | 3,773,728 |
| „ consumption | | 3,833,940 |
| Coal production | | 1,132,625 |
| „ consumption | | 2,399,025 |
| Coke production | | 25,550 |
| „ consumption | | 270,361 |

Austria consumes 59 per cent. and exports 41 per cent. of the lignite produced, produces 75·2 per cent. and imports 24·8 per cent. of the coal needed, and produces 85·4 per cent. and imports 14·6 per cent. of the coke needed. Hungary produces 98·1 per cent. of the brown coal needed and imports 1·9 per cent., produces 47·2 per cent. and imports 52·8 per cent. of the coal needed, and produces 9·4 per cent. and imports 90·6 per cent. of the coke needed.

IV.—BELGIUM.

Mineral Statistics.—The mineral statistics in the *Moniteur des Intérêts Matériels* for February 16, 1899, show that in Belgium there were in 1898 in operation 113 collieries, the total production being 22,075,093 tons of coal. The iron trade production in 1898 † comprised:—

| | Metric Tons. |
|---------------------------------|--------------|
| Foundry pig iron | 93,645 |
| Forge pig iron | 309,477 |
| Steel-making pig iron | 575,979 |
| Total pig iron | 979,101 |
| Wrought iron | 509,160 |
| Steel ingots | 653,130 |
| Forged steel | 558,995 |

In 1897, in the Belgian collieries,‡ the number of workpeople employed in 1897 was 120,382, each of whom earned nearly £40, 18s., on the average, in the course of the year. The corresponding figures for the previous year were 119,246 and £39, 4s. The consumption of coal in Belgium has increased from 15,073,084 tons in

* *Zeitschrift des Oesterreichischen Ingenieur und Architekten Vereins*, vol. 1. pp. 426-431.

† *Comité des Forges*, Bulletin No. 1424. ‡ *Stahl und Eisen*, vol. xix. pp. 326-328.

1891 to 17,637,670 tons in 1897, while the exports have diminished from 4,750,232 tons in 1891 to 4,448,544 tons in 1897, the greater portion of which was exported to France. The imports of coal into Belgium have increased from 1,288,640 tons in 1893 to 2,017,344 tons in 1897, more than the half of which was from Germany.

The production of coke in Belgium was 2,207,840 tons with a consumption of 2,968,620 tons of coal, the yield being 74·3 per cent. In 1895 the yield was 74·1 per cent., the production of coke having been 1,749,109 tons from 2,358,663 tons of coal. The coke-works in Belgium in 1897 numbered 45. These possessed 3845 active coke-ovens and 995 not in use. The workpeople employed numbered 2566. The coke imported into Belgium in 1897 amounted to 269,606 tons, 173,519 tons of which was from Westphalia. The exports of coke amounted to 909,486 tons, an increase of over 46,000 tons as compared with the imports in 1896. The production of briquettes has also increased of late in Belgium. In 1897 there were 37 briquette-making works, possessing 71 presses in use and 13 not in use. They made 1,245,114 tons of briquettes from 1,129,781 tons of coal. The imports of briquettes amounted to 3686 tons, and the exports to 358,691 tons.

The output of iron ore shows a diminution of 27 per cent. on the year. In 1897 it was 240,774 tons, the output of manganese ore being 28,372 tons—an increase of about 22 per cent. as compared with the output in 1896; the value, however, showed a diminution. The total quantity of iron ore smelted in Belgian blast-furnaces in 1897 was 283,992 tons of native ore and 2,202,208 tons of imported ore, and 270,927 tons of slag and scrap, with 393,113 tons of limestone, was also charged. At seventeen works thirty-six blast-furnaces were in blast. Two works with six blast-furnaces were idle. The workpeople employed numbered 3476, and these earned an average daily wage of 3·11 francs—say half-a-crown. The following table shows the production of the various kinds of pig iron in Belgium in 1896 and 1897:—

| | 1896. | 1897. |
|-----------------------------|--------------|--------------|
| | Metric Tons. | Metric Tons. |
| Forge pig iron | 362,451 | 426,332 |
| Foundry pig iron | 84,275 | 78,410 |
| Ferro manganese | 11,391 | 12,636 |
| Bessemer pig iron | 193,518 | 183,701 |
| Basic pig iron | 307,779 | 333,958 |

The value per ton showed a considerable increase in each case, as the following table shows :-

| Value per Ton. | | | |
|-----------------------------|--|---------|---------|
| | | 1896. | 1897. |
| | | Francs. | Francs. |
| Forge pig iron | | 51.52 | 54.57 |
| Foundry pig iron | | 47.81 | 58.17 |
| Ferro-manganese | | 67.67 | 79.02 |
| Bessemer pig iron | | 59.03 | 64.70 |
| Basic pig iron | | 54.20 | 59.90 |

In the case of foundry pig iron this increase was as much as nearly 21 per cent.

In the manufacture of malleable iron a diminution is observable, but there was an increase in the average value per ton. There were 47 weld-iron works active and 3 idle. The total production amounted to 474,819 tons, valued at 135.61 francs per ton. The puddling furnaces that were active numbered 339, while 74 were idle. The workpeople employed numbered 15,103. They earned on the average 3.45 francs per day.

A continuance is observable in the increasing manufacture in Belgium of ingot metal, though at a less rapid rate. Thus the production of this material in Belgium was 367,947 tons in 1895, 519,311 tons in 1896, and 527,617 tons in 1897. The average value per ton in 1897 was 15 per cent. higher than it was in 1895. The active ingot-iron works numbered 11, while 2 were idle. These possessed 17 active Bessemer converters and 15 not in use, and also 9 open-hearths active and 4 idle, together with 44 active heating furnaces and 19 not in work. The workpeople employed numbered 5876, the average daily wage being 3.50 francs. The total quantity of the products was 527,617 tons, of the average value of 132.34 francs per ton. This included 136,911 tons of rails, and 272,839 tons of other rolling-mill products, in addition to 64,366 tons of sheets, 19,527 tons of wire, and 10,870 tons of tires. The production of ingots was 616,541 tons.

The imports and exports of iron and steel into Belgium have been as follows, in metric tons :—

| | Imports. | | Exports. | |
|------------------------|----------|---------|----------|---------|
| | 1896. | 1897. | 1896. | 1897. |
| Pig iron | 314,555 | 288,956 | 10,744 | 10,381 |
| Finished products :— | | | | |
| Weld iron | 22,812 | 28,447 | 343,072 | 356,835 |
| Ingot iron | 22,865 | 25,869 | 179,873 | 183,386 |
| Steel ingots | 28,434 | 25,370 | 1,145 | 1,201 |

The total consumption of pig iron in Belgium was 1,263,225 tons in 1896 and 1,313,612 tons in 1897, and of steel ingots 626,263 tons in 1896 and 640,710 tons in 1897.

The *Annuaire Statistique de la Belgique*, which was issued in February 1899 by the Minister of the Interior, contains the mineral statistics for 1896. There were in that year in operation in Belgium 1560 quarries, employing 32,601 men, and raising mineral worth 40,973,662 francs. The production of the metal mines included :—

| | Quantity. | Value. |
|-------------------------|-----------|-----------|
| | Tons. | Francs. |
| Iron ore | 307,031 | 1,417,820 |
| Manganese ore | 23,265 | 345,020 |

There were 2017 miners employed, the mean daily wage being 2·36 francs. Of coal 21,252,370 tons were raised, 119,246 workpeople being employed.

V.—CANADA.

Mineral Statistics.—A statement issued subject to revision* shows that the mineral production of the Dominion in 1898 included—

| | Tons. |
|--------------------|-----------|
| Iron ore | 51,929 |
| Coal | 3,725,585 |
| Coke | 64,682 |

The value of the natural gas produced was 320,000 dollars, and the production of petroleum amounted to 700,790 barrels.†

According to G. E. Drummond,‡ the year 1898 marks a new era in

* *Annual Statistical Report of the American Iron and Steel Association*, 1899, p. 75.

† *Engineering and Mining Journal*, p. 262.

‡ *Canadian Mining Review*, vol. xviii. pp. 56-57.

the iron industry of Canada as the beginning of a modern expansion in the manufacture of pig iron. The total out-turn of pig iron in Canada, according to his estimate, was 57,904 tons.

The production of pig iron in the Dominion of Canada in 1898, as ascertained by the American Iron and Steel Association, was 68,755 tons, against 53,796 tons in 1897. The production of open-hearth and Bessemer steel was 21,540 tons, against 18,400 tons in 1897, and that of all kinds of iron and steel rolled into finished forms was 90,303 tons, against 77,021 tons in 1897.

Canada has now nine completed blast-furnaces, seventeen rolling-mills, one Bessemer plant, and one open-hearth steel plant. A new charcoal blast-furnace at Deseronto, Ontario, was blown in on January 25, 1899.

The Mining Industry of Nova Scotia.—The report for 1898 on the mines of Nova Scotia has been issued.* The following summary shows the mineral production for the year ending September 30, compared with that for the year ending September 30, 1897.

| | Year ending Sept. 30, 1897. | Year ending Sept. 30, 1898. |
|-------------------------|--------------------------------|--------------------------------|
| | Tons. | Tons. |
| Iron ore | 44,146 | 31,050 |
| Manganese ore | 100 | 75 |
| Coal raised | 2,320,916 | 2,281,454 |
| Coke made | 45,000 | 42,000 |
| Limestone | 25,000 | 24,000 |

The mining industry of Nova Scotia in 1898 was in a fairly satisfactory condition. The furnace of the Nova Scotia Steel Company at Ferrona consumed 70,000 tons of coal, 30,000 tons of coke, and 22,000 tons of pig iron were made. At Londonderry no pig iron was made, operations being confined to the foundry.

E. Gilpin † gives the regulations concerning underground certificates in Nova Scotian mines.

The Mining Industry of Newfoundland.—According to a return furnished by J. P. Howley, Director of the Geological Survey of Newfoundland, the production of iron ore in that colony during 1897 amounted to 58,940 tons, against 38,450 tons in the previous year. Newfoundland is not embraced in the Dominion of Canada.

* *Report of the Department of Mines for Nova Scotia, 1899.*

† *Transactions of the Institution of Mining Engineers*, vol. xvi. pp. 300-315.

VI.—FRANCE.

Iron Trade Statistics.—The production * of iron and steel in France in 1898 (provisional figures) and in 1897 (definite figures) was as follows :—

| | 1897. | 1898. |
|------------------------------|--------------|--------------|
| | Metric Tons. | Metric Tons. |
| Forge pig iron | 1,962,370 | 1,985,413 |
| Foundry pig iron | 521,821 | 549,014 |
| Total pig iron | 2,484,191 | 2,534,427 |
| Iron rails | 593 | 230 |
| Merchant iron | 704,324 | 721,230 |
| Plates | 79,049 | 80,083 |
| Total wrought iron | 783,966 | 801,543 |
| Steel rails | 191,860 | 222,054 |
| Merchant steel | 568,998 | 651,733 |
| Steel plates | 234,033 | 264,846 |
| Total steel | 994,891 | 1,138,633 |
| Bessemer ingots | 802,326 | 905,995 |
| Open-hearth ingots | 522,887 | 535,638 |
| Total steel ingots | 1,325,213 | 1,441,633 |

The definite official statistics † which have been published show that the production of pig iron in France in 1897 amounted to 2,484,191 tons. There were sixty-one ironworks with 111 blast-furnaces in operation. Of the iron ore consumed 4,282,000 tons were of native production, 65,000 tons were imported from Algeria, and 2,073,000 tons were imported from other countries. Of fuel there was consumed 3,006,000 tons of coke, 26,500 tons of raw coal, and 14,000 tons of charcoal.

The *Comité des Forges* ‡ publishes particulars of the iron ore industry of France and Algeria in 1897. There were seventy-eight iron mines in operation in France and four in Algeria. The production of iron ore in France was as follows :—

| | |
|-------------------------------|-----------|
| | Tons. |
| Oolitic iron ore | 1,120,000 |
| Brown hæmatite | 102,000 |
| Other hydrated ores | 143,500 |
| Red hæmatite | 177,000 |
| Spathic ore | 39,500 |
| Total | 4,582,000 |

The number of workmen employed was 8000. In Algeria the production amounted to 441,500 tons.

* *Comité des Forges*, Bulletin No. 1432.

† *Statistique de l'Industrie minière*; *Comité des Forges*, Bulletin Nos. 1407, 1408.

‡ Bulletin Nos. 1405, 1416.

Imports and Exports.—The total exports of iron and steel from France in the year 1898 amounted to 373,124 tons, which is an increase on the exports of 1897 to the extent of 61,089 tons, or 19·57 per cent. A feature of the exports of the period named has been the large increase in the exports of pig iron, which rose from 108,609 to 161,782 tons. The exports otherwise have been :—

| | 1897. | 1898. |
|-----------------------------|--------|--------|
| | Tons. | Tons. |
| Finished iron | 55,786 | 52,031 |
| Finished steel | 46,343 | 47,562 |
| Re-exports of finished iron | 11,374 | 12,869 |
| Re-exports of steel . . . | 3,676 | 3,317 |
| Re-exports of plates . . | 3,243 | 2,380 |

The chief individual items of export have been bar iron, which fell from 40,113 tons to 27,622 tons, and billets and ingots, which rose from 31,568 tons to 37,193 tons.

The imports of iron and steel into France in the same two years have been as under, in metric tons :—

| | 1897. | 1898. |
|---------------------------|---------|---------|
| Pig iron | 63,481 | 65,925 |
| Finished iron | 23,894 | 22,012 |
| Steel | 6,233 | 6,352 |
| Temporary imports | 112,653 | 123,648 |

The temporary imports, which are admitted duty free on being declared as intended for re-export, included 99,241 tons of pig iron, 13,353 tons of finished iron, and 4206 tons of steel other than plates.*

The increase of the importation of coal from England as compared with Belgium into France is shown in the following table :†—

| | Metric Tons. | | |
|-----------------------------------|--------------|-----------|-----------|
| | 1895. | 1896. | 1897. |
| Total imports of coal into France | 8,748,100 | 8,757,655 | 8,923,320 |
| Imported from Belgium . . | 3,868,648 | 3,741,593 | 3,534,030 |
| Imported from the United Kingdom | 4,289,498 | 4,371,211 | 4,708,930 |

* *Comité des Forges*, Bulletin No. 1400.

† *Stahl und Eisen*, vol. xix. p. 326.

VII.—*GERMANY.*

Mineral Statistics.—The preliminary mineral statistics of the German Empire and Luxemburg for 1898 has just been issued by the Imperial Statistical Department.* The production comprised—

| | Tons. |
|------------------------|------------|
| Coal | 96,279,992 |
| Brown coal | 31,648,498 |
| Petroleum | 25,789 |
| Iron ore | 15,893,246 |
| Iron pyrites | 136,849 |

Statistics† collected by the Society of German Ironmasters show that the consumption and production of pig iron per head of population in the German Empire and Luxemburg increased during the years 1861 to 1898 in the following manner:—

| | Consumption. | Production. |
|------|--------------|--------------|
| | Kilogrammes. | Kilogrammes. |
| 1861 | 25·2 | 21·8 |
| 1872 | 59·3 | 43·9 |
| 1882 | 51·5 | 74·8 |
| 1892 | 74·3 | 98·8 |
| 1893 | 72·5 | 98·7 |
| 1895 | 71·9 | 105·1 |
| 1896 | 90·1 | 121·4 |
| 1897 | 104·1 | 129·8 |
| 1898 | 104·3 | 135·2 |

Iron Trade Statistics.—The statistics collected by the Society of German Ironmasters‡ show the production of pig iron in Germany, including Luxemburg, to have been as follows in 1898:—

| | Production. | Per Cent of Total in 1898. | Per Cent of Total in 1897. |
|---|--------------|----------------------------|----------------------------|
| | Metric Tons. | | |
| Forge pig iron and spiegeleisen | 1,564,149 | 21·1 | 23·5 |
| Bessemer pig iron | 534,674 | 7·2 | 8·2 |
| Basic pig iron | 4,002,126 | 54·1 | 51·9 |
| Foundry pig iron | 1,301,768 | 17·6 | 16·4 |
| Totals | 7,402,717 | 100·0 | 100·0 |

* *Verein Deutscher Eisen- und Stahl-Industrieller*, 1899, No. 9.

† *Ibid.*, 1899, No. 10.

‡ *Ibid.*, 1899, No. 2.

The production of pig iron in the previous year amounted to 6,889,067 tons or 6,881,466 tons, as shown by the Association statistics and the official statistics respectively. Details are given showing the production of the various iron-producing districts into which the Empire may be divided, Rhenish Westphalia taking the premier position, with 2,990,325 tons; then the Saar district, Lorraine and Luxemburg, with 2,528,790 tons; Silesia and Pomerania with 747,731 tons; and the Siegen district, with the districts of the Lahn and Hesse-Nassau standing fourth with a production of 657,491 tons. It is interesting to observe that these last two districts produced together 52·8 per cent. of the total quantity of forge pig iron and spiegeleisen, the first and second districts, while possessing a total output more than four times as large as that of the other two, only producing 44·5 per cent. of the forge pig iron and spiegeleisen. No Bessemer pig iron was produced in the district of the Saar, Lorraine, and Luxemburg, while 74·6 per cent. of the total production of this variety of metal was made in Rhenish Westphalia.

The production of pig iron in Germany, including Luxemburg, in 1898, as well as the imports into and exports from the country, are stated to have been as follows, the production being that estimated from the statistics collected by the Society of German Ironmasters, and the exports and imports from the official returns : *—

| | Metric Tons. |
|----------------------|--------------|
| Production | 7,402,717 |
| Imports | 407,887 |
| Exports | 272,470 |

The imports thus exceeded the exports by 135,417 tons. With the exception of 1894 and 1895, in each of which years the exports exceeded the imports by about 20,500 tons, Germany has been an importing country for pig iron since 1887. In that year the total consumption of pig iron in Germany was estimated at 3,915,048 tons as compared with 7,538,134 tons in 1898.

A general comparison † is drawn between the iron trade production of Germany, including Luxemburg, in the years 1895, 1896, and 1897, the various items being separately distinguished. From these the following are taken :—

* *Verein deutscher Eisen- und Stahl-Industrieller*, 1899, No. 4.

† *Stahl und Eisen*, vol. xix. pp. i.

| | 1895. | 1896. | 1897. |
|--|------------|------------|------------|
| Producing iron ore mines | 491 | 542 | 586 |
| Iron ore mined, metric tons | 12,349,600 | 14,162,335 | 15,465,979 |
| Value per ton, shillings | 3·32 | 3·62 | 3·88 |
| Workpeople employed | 33,556 | 35,223 | 37,991 |
| Coal raised, metric tons | 79,169,276 | 85,690,233 | 91,054,982 |
| Brown coal raised, metric tons | 24,788,363 | 26,780,873 | 29,419,503 |
| Workpeople at collieries | 303,937 | 316,513 | 336,174 |
| Workpeople at brown coal mines | 37,476 | 38,195 | 40,057 |
| Value per ton of coal, shillings | 6·85 | 6·96 | 7·17 |
| Value per ton of brown coal, shillings | 2·38 | 2·32 | 2·30 |
| Active blast-furnace plants | 104 | 106 | 109 |
| Charcoal pig iron made, tons | 16,879 | 16,385 | 16,509 |
| Coke and mixed fuel pig iron, tons | 5,447,622 | 6,356,190 | 6,864,957 |
| Average value per ton, shillings | 43·36 | 47·02 | 50·88 |
| Ores and slags treated, tons | 13,765,799 | 15,892,672 | 17,127,993 |
| Workpeople employed | 24,059 | 26,562 | 30,459 |
| Total blast-furnaces | 263 | 265 | 273 |
| Active blast-furnaces | 212 | 229 | 242 |
| Weeks in blast | 9,929 | 10,846 | 11,661 |
| Active foundries | 1,280 | 1,267 | 1,216 |
| Workpeople | 67,903 | 74,536 | 79,844 |
| Pig iron and scrap melted, tons | 1,341,302 | 1,570,155 | 1,680,989 |
| Castings made, tons | 1,172,435 | 1,384,008 | 1,473,211 |
| Average value per ton, shillings | 160·91 | 166·36 | 171·48 |
| Producing weld iron works | 210 | 193 | 186 |
| Workpeople employed | 38,190 | 39,684 | 39,958 |
| Semi-manufactures made, tons | 84,068 | 86,700 | 79,893 |
| Value per ton, shillings | 71·27 | 83·09 | 92·46 |
| Manufactures made, tons | 996,202 | 1,113,559 | 1,031,691 |
| Value per ton, shillings | 115·97 | 128·34 | 137·61 |
| Producing ingot iron works | 151 | 154 | 164 |
| Workpeople employed | 75,080 | 83,302 | 91,526 |
| Semi-manufactures made, tons | 1,131,457 | 1,358,245 | 1,273,089 |
| Value per ton, shillings | 70·99 | 77·73 | 84·15 |
| Manufactures made, tons | 2,831,318 | 3,462,736 | 3,863,469 |
| Value per ton, shillings | 117·45 | 125·70 | 131·02 |

During the ten years 1888–97 the value of the iron ores raised, and pig iron, iron and steel made in Germany and Luxemburg, has increased from £28,502,503 in 1888 to £50,988,720 in 1897, the mark being considered equal to one shilling. The number of workpeople employed varied as follows:—

| Year. | Iron Ore Mines. | Blast-Furnace Plants. | Foundries, Iron and Steel Works. |
|----------------|--------------------|--------------------------|--|
| 1874 | 31,733 | 24,342 | 118,748 |
| 1880 | 35,814 | 21,117 | 106,968 |
| 1885 | 36,072 | 22,768 | 130,755 |
| 1890 | 38,837 | 24,846 | 170,753 |
| 1895 | 33,556 | 24,059 | 181,173 |
| 1897 | 37,991 | 30,459 | 211,328 |

The total number of workpeople employed has thus increased by about 60 per cent. during this period.

In Germany steel production continues to grow steadily. The German Ironmakers' Union reports the output last year as follows, in metric tons :—

| | 1897. | | 1898. | | Increase. |
|---------------------|-----------|-----------|-----------|-----------|-----------|
| | Tons. | Per Cent. | Tons. | Per Cent. | Tons. |
| Converter | 3,234,214 | 71·3 | 3,606,737 | 71·2 | 372,523 |
| Open-hearth | 1,304,423 | 28·7 | 1,459,159 | 28·8 | 154,736 |
| Totals | 4,538,637 | 100·0 | 5,065,896 | 100·0 | 527,229 |

The Iron Ore Districts.—A shaded map is published * showing the annual production of iron ore in the various portions of Germany. The largest portion of the production is from the so-called Minette district, which yields approximately two-thirds of all the ore mined in Germany. Next in productivity is the Grauwacke formation of the Siegen and neighbouring districts, which yields over 2,000,000 tons, chiefly spathic ore and brown hæmatite. The Harz district yields about 500,000 tons, Upper Silesia, Bavaria, and Hesse each yielding somewhat less than this. The other districts are of less importance. In Prussia in 1897, 4,183,536 tons of iron ore were raised from 388 mines, as compared with 4,053,108 tons in 1896 from 360 mines.

Production of Basic Steel.—The production of basic steel † in Germany in 1898 amounted to 5,065,896 tons, of which 3,606,737 tons consisted of basic Bessemer steel and 1,459,159 tons of basic open-hearth steel. The rapid development of the manufacture of basic steel in Germany is well shown by the following statistics of production :—

| Year. | Tons. |
|----------------|-----------|
| 1894 | 3,241,272 |
| 1895 | 3,539,203 |
| 1896 | 4,297,447 |
| 1897 | 4,538,637 |
| 1898 | 5,065,896 |

Mineral Statistics of Prussia.—The following are additional details relating to the mineral statistics of Prussia in 1897: ‡—

* *Stahl und Eisen*, vol. xix. p. 156.

† *Verein deutscher Eisen- und Stahl-Industrieller*, 1899, No. 6.

‡ *Zeitschrift für das Berg-, Hütten- und Salinenwesen im preussischen Staate*, vol. xlv., Statistics; see also *Journal of the Iron and Steel Institute*, 1898, No. II. p. 578.

| | Active Mines or Works. | Production. Metric Tons. |
|----------------------------------|---------------------------|-----------------------------|
| Coal | 258 | 84,253,393 |
| Brown coal | 368 | 24,222,911 |
| Asphalt | 3 | 11,466 |
| Petroleum | 6 | 2,600 |
| Iron ore | 388 | 4,183,536 |
| Manganese ore | 7 | 45,253 |
| Charcoal pig iron | 8 | 13,425 |
| Coal and coke pig iron | 74 | 4,878,633 |

The workpeople employed in collieries and brown coal mines, &c., numbered 335,667, and in ore mining of all kinds 64,933. These statistics do not include those for the Principality of Waldeck. The number of works at which pig iron was made numbered eighty-two. With regard to forty-four of these, which chiefly served for the general pig iron production, the blast-furnaces were as follows :—

| | Total. | Active. | Weeks in Blast. |
|----------------------------------|--------|---------|--------------------|
| Charcoal furnaces | 12 | 8 | 286 |
| Coal and coke furnaces | 189 | 167 | 8072 |
| Totals | 201 | 175 | 8358 |

The total number of miners under supervision in Prussia numbered in 1897 415,638, and of these 883 lost their lives by accidents. Of these, 714 lives were lost in the collieries, 78 in the brown coal mines and 68 in the ore mines, 23 deaths being in connection with the mining of salt and other minerals. Details are given as to the way in which these accidents occurred. The average annual wage earned by a coal-miner varied in different districts, from a minimum of £36 in Upper Silesia, to a maximum of over £56 in the Dortmund district.

Full statistics relating to the Prussian railway system are published in *Stahl und Eisen*.*

Mineral Statistics of Saxony.—In 1897 there were in Saxony † 35 collieries and 106 brown coal mines. Of iron ore 13,181 tons was mined, and of manganese ore 260 tons. The coal and anthracite raised amounted to 4,571,685 tons, and the brown coal to 1,073,239 tons. From 156,123 tons of coal there were made 77,507 tons of coke

* Vol. xix. pp. 116-125.

† *Jahrbuch für das Berg- und Hüttenwesen im Königreiche Sachsen auf das Jahr 1898*, p. 80. Freiberg, 1899.

and 3547 tons of briquettes; and from 231,789 tons of brown coal 53,460 tons of briquettes in addition to 60,166,000 "brown coal bricks."

In all the mines of Saxony there were employed 28,895 workpeople, of whom 22,000 were engaged in coal-mining, and 2120 at the brown coal mines. The total number of fatal accidents during the year was 51, 38 being at coal mines and 8 at brown coal mines.

Iron Trade Statistics of Lorraine and Luxemburg.—The iron trade statistics for Lorraine and Luxemburg are as follows for the years mentioned : *—

| | 1896. | 1897. |
|--------------------|--------------|--------------|
| | Metric Tons. | Metric Tons. |
| Coal | 1,027,699 | 1,057,544 |
| Iron ore | 4,841,598 | 5,360,586 |
| Pig iron | 919,848 | 927,944 |
| Castings | 18,045 | 19,229 |
| Bar iron | 98,818 | 74,322 |
| Steel | 209,923 | 241,524 |

Coal in Upper Silesia.—According to official statistics, the production of coal in Upper Silesia in 1898 showed a decided increase, the output having amounted to 22,489,883 tons, or 9 per cent. more than in 1897. During the last twenty years the output has increased 252 per cent.

Production of Coke in Westphalia.—The report of the Westphalian Coke Syndicate for last year shows that the total number of coke-ovens in operation at the end of the year was 8082, of which 2100 were by-product ovens. The production was as follows :—

| | Tons. |
|---|-----------|
| Coke-ovens belonging to the Syndicate | 6,415,683 |
| Three works not forming part of the Syndicate | 163,154 |
| Collieries belonging to ironworks | 795,483 |
| Total | 7,374,320 |

This represents a value of £4,800,000, and an increase in quantity of 7·3 per cent. as compared with the coke production of 1897. In ten years the production has doubled.

* *Zeitschrift für praktische Geologie*, 1899, p. 29.

Coal Imports and Exports.—Imports and exports of fuel into and from Germany for the calendar year were as follows in metric tons :—

| | Imports. | | Exports. | |
|----------------------|-----------|-----------|------------|------------|
| | 1897. | 1898. | 1897. | 1898. |
| Coal | 6,072,029 | 5,820,332 | 12,389,907 | 13,989,223 |
| Brown coal | 8,111,076 | 8,450,149 | 19,112 | 22,155 |
| Coke | 435,161 | 332,578 | 2,161,886 | 2,133,179 |
| Briquettes | 79,450 | 62,239 | 247,722 | 325,408 |

This shows a surplus of exports over imports in 1898 of 8,168,891 tons of coal, 1,800,601 tons of coke, and 263,169 tons of briquettes ; an excess of imports of 8,427,994 tons of brown coal.

VIII.—INDIA.

The Iron Trade.—The annual statement of the trade of British India with British possessions and foreign countries for the year 1897–98 has been issued. It shows that the imports of iron and steel into India for the last five years were as under :—

| Iron. | | Steel. | |
|-------------------|-----------|-------------------|-----------|
| | Cwt. | | Cwt. |
| 1893–94 | 3,709,617 | 1893–94 | 1,039,819 |
| 1894–95 | 3,250,403 | 1894–95 | 905,333 |
| 1895–96 | 4,000,246 | 1895–96 | 1,702,253 |
| 1896–97 | 3,892,843 | 1896–97 | 1,553,181 |
| 1897–98 | 3,945,364 | 1897–98 | 1,848,704 |

There was a rise last year in both cases, and notably in steel, for which the figures are the highest tabulated. The use of steel for rolled beams, girders, bars, and hooping, which were formerly made of iron, is increasing.

IX.—ITALY.

The Iron Industry.—The quantity of iron ore raised in Elba * in 1897 amounted to 200,729 tons, as compared with 203,966 tons in the previous year. The manganese ore raised was 1634 tons in 1897 and

* *Rassegna Mineraria*, vol. iv. pp. 236 and 250 ; *Stahl und Eisen*, vol. xix. p. 99 ; see also *Journal of the Iron and Steel Institute*, No. II. 1898, p. 583.

1890 tons in 1896. Of manganiferous brown iron ore 21,262 tons was raised in 1897 and 10,000 tons in 1896. There were in operation thirteen iron ore mines, five manganese ore mines, and one brown iron ore mine. Of the total output of iron ore 198,316 tons was raised in Elba, 863 tons in Lombardy, and the small remainder in Piedmont. The exports of Elba ores amounted to 257,600 tons in 1897, 219,162 tons in 1896, and 145,629 tons in 1895. Of the 257,660 tons exported in 1897, 171,548 tons were sent to the United Kingdom.

In 1897 six blast-furnaces were in operation. These made together 8393 tons of pig iron, 3680 tons of which was made in Lombardy, and the remainder at the Follonica Works. Of weld iron 149,944 tons was made, while the production of ingot iron and steel amounted to 63,940 tons, and of the tin-plate to 6500 tons.

The total number of all the iron and steel works was 216. These gave employment to 12,991 workpeople. Of coal and brown coal 314,222 tons were raised in 1897, as compared with 276,197 tons in 1896. The number of the collieries amounted to twenty-nine, and of workpeople employed at them to 2211. The manufacture of open-hearth steel is making important progress in Italy, and the iron trade generally was in a very satisfactory condition in 1897. The quantity of petroleum raised was 1932 tons.*

X.—RUSSIA.

Iron Trade Statistics.—The production of iron and steel in Russia in 1897 has already been given in the *Journal of the Iron and Steel Institute*.† It is now stated * that there were in blast in Southern Russia in 1897 twenty-five blast-furnaces, with a total out-turn of 754,000 metric tons of pig iron, or on the average 30,160 tons per annum and per furnace. In 1898 the number of active furnaces in the district in question increased to thirty, while eleven others are in process of erection, and arrangements are being made for the erection of two more. It follows that instead of the twenty-five blast-furnaces of 1897, forty-three will soon be at work. The pig iron out-turn of Southern Russia is thus making very rapid strides. It is estimated

* *Rivista del Servizio Minerario nel 1897.*

† 1898, No. II. p. 584.

‡ *Russische Reichsanzeiger*, Nov. 18, 1898, through *Stahl und Eisen*, vol. xviii. p. 1155.

that the total production of pig iron in Russia in 1898 will exceed the out-turn in 1897 by about 17·5 per cent. The following are the estimates for the production of pig iron in the various districts of the Empire in 1898 :—

| | 1898. | 1897. |
|---------------------------|--------------|--------------|
| | Metric Tons. | Metric Tons. |
| South Russia | 1,000,000 | 754,000 |
| Urals | 705,000 | 672,000 |
| Other districts | 492,000 | 443,000 |
| Totals | 2,197,000 | 1,869,000 |

The iron industry of Russia is making astonishing progress.* In 1897 the production was 15 per cent. higher than it was in the previous year. In the past decade the production of pig iron in Russia has trebled, and the Russian Government has expressed the hope that in the very near future the whole of the home requirements of pig iron will be met by the out-turn of Russian works. Rapid as has been the progress made in the production of pig iron, equally or even more rapid has been the increase in the consumption of iron in Russia. Up to the present only a diminution in the imports of pig iron is observable, while there has actually been a considerable increase in the imports of iron and steel, and in particular of machinery. The new steelworks at Zarizin and Saratow will lead to a further increase in the consumption of pig iron. These works will require some 250,000 tons of pig iron annually. The ore question has become a serious difficulty for the ironworks of South Russia. The Russian Government is doing all it can to foster the iron industry. Transport charges have been diminished on the railways, and the market cost of pig iron has consequently diminished. Details are given as to the selling prices of several varieties of Russian and imported pig iron at the commencement and close of the year 1897. Russia is making great strides in internal progress. Works and railways are being rapidly constructed, and these in turn lead to a rapid increase in the home iron trade, though this latter is still unable to keep pace with the consumption, great though its progress has been.

Production of Pig Iron in Russia.—The following table shows the production of pig iron in the whole of Russia and in the South

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlv. pp. 603-605.

of Russia, in poods (62·0257 poods = 1 ton). The number of blast-furnaces in South Russia in each of the years in question is also shown :—

| Production of Pig Iron. | | | |
|-------------------------|-------------|--------------------|---------|
| All Russia. | | South Russia only. | |
| Production. | Production. | Production. | Number. |
| Poods. | Poods. | Poods. | Number. |
| 1887 | 37,389,300 | 3,999,000 | 5 |
| 1888 | 40,715,700 | 5,300,000 | 6 |
| 1889 | 45,560,800 | 8,670,000 | 8 |
| 1890 | 56,560,100 | 13,228,000 | 9 |
| 1891 | 61,339,700 | 15,239,000 | 11 |
| 1892 | 65,431,700 | 17,029,000 | 12 |
| 1893 | 69,337,700 | 19,868,000 | 13 |
| 1894 | 79,706,900 | 27,152,000 | 13 |
| 1895 | 86,852,968 | 33,675,000 | 13 |
| 1896 | 96,919,400 | 38,995,000 | 17 |
| 1897 (approx.) | 111,000,000 | 62,500,000 | 25 |

As will be seen from the above table, nearly the whole of the enormous increase in the production is due to the increase in the output of the works in the South of Russia. Here transport facilities have very greatly improved in recent years. The consumption of pig iron per inhabitant in Russia increased from 29 lbs. in 1893 to about 42 lbs. in 1896.*

The *Bulletin* of the Committee of French Ironmasters for December 29 contains particulars of the production of pig iron in South Russia. In 1897 there were twelve ironworks in operation. Five others are in course of construction, and these will, without doubt, bring the number of blast-furnaces in South Russia in 1899 up to thirty-one. The year's output should then be 1,500,000 tons.

A series of articles have appeared † dealing with the coal and iron resources of Russia. The number and areas of the concessions are given, with particulars of the railways, &c., in the Caucasus.

Imports and Exports.—The Russian imports and exports in 1896 and 1897 included : ‡—

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlv. pp. 629-630.

† *Iron and Coal Trades Review*, vol. lviii. p. 285, &c.

‡ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlv. p. 759; see also *Journal of the Iron and Steel Institute*, 1898, No. II. p. 585.

| | In Quantities of 1000 Poods (say 16·1 Tons). | | | |
|--------------------------------------|---|---------|----------|--------|
| | Imports. | | Exports. | |
| | 1896. | 1897. | 1896. | 1897. |
| Coal | 120,854 | 129,569 | 560 | 2,024 |
| Coke | 21,248 | 24,414 | ... | ... |
| Pitch, asphalt, &c. | 184 | 418 | ... | ... |
| Ozokerite | 108 | 91 | ... | ... |
| Illuminating oil | ... | ... | 52,744 | 49,756 |
| Lubricating oil, unrefined | ... | ... | 2,061 | 2,424 |
| Lubricating oil, refined | ... | ... | 5,325 | 6,471 |
| Petroleum residues | ... | ... | 3,002 | 3,798 |
| Manganese ores | ... | ... | 8,842 | 11,441 |

Manganese Ore.—The exports of manganese ore from the Caucasus in 1893 and 1897 were as follows:—

| To | 1893. | 1897. |
|-------------------------|---------|---------|
| | Tons. | Tons. |
| Great Britain | 42,930 | 68,650 |
| France | 4,100 | ... |
| Russia | ... | 28,446 |
| Belgium | 3,125 | ... |
| Germany | 40,405 | 70,810 |
| United States | 36,070 | 42,200 |
| Totals | 126,630 | 210,106 |

It will be seen that Great Britain, though still a large importer, has yielded the first place to Germany.

Petroleum.—In an appendix to a return of the world's coal supply prepared by A. E. Bateman * for the House of Commons, statistics are given of the petroleum production and trade in Russia for a number of years. The steady increase in the Russian production has been very remarkable, the output having risen from 167,000,000 gallons in 1881 to 1,884,000,000 gallons in 1897. The Russian output is about 89 per cent. of the American production, which amounted to 2,119,000,000 gallons in 1897. In Russia, 84 per cent. of the total production is consumed at home, whilst in the United States the corresponding proportion is 60 per cent.

* "Coal Tables," Parliamentary Paper No. 118 of Session 1899.

XI.—*SOUTH AFRICAN REPUBLIC.*

Coal.—The production of the collieries of the South African Republic in 1898 was as follows : *—

| | Tons. |
|----------------------|-----------|
| Boksburg | 1,274,646 |
| Heidelberg | 313,958 |
| Middelburg | 305,151 |
| Leydenburg | 33,103 |
| Various | 26,168 |
| Total | 1,953,026 |

The coal had an average value of 7·01s. per ton. The number of miners employed amounted to 391 whites and 6901 natives.

XII.—*SPAIN.*

Iron Ore.—The detailed figures of the Spanish production of iron ore in 1898 have been published.† These figures show a decrease of 294,168 metric tons, or about 4 per cent. under 1897. The decrease in the output is almost entirely due to the province of Vizcaya, which produced, in 1898, 280,000 metric tons less than in 1897. The Orconera Company shows a decreased output for the year of 73,407 metric tons, while that of the Franco-Belge Company has increased by 124,000 tons, both figures being compared with those of the previous year.

Production of Iron Ore.

| Province. | 1897. | 1898. |
|---------------------|--------------|--------------|
| | Metric Tons. | Metric Tons. |
| Vizcaya | 5,254,492 | 4,973,000 |
| Santander | 749,404 | 790,000 |
| Murcia | 426,400 | 416,000 |
| Sevilla | 388,443 | 391,000 |
| Almeria | 395,165 | 363,000 |
| Oviedo | 58,107 | 64,000 |
| Granada | 47,483 | 52,000 |
| Malaga | 35,014 | 22,100 |
| Huelva | 28,640 | 17,500 |
| Guipuzcoa | 16,472 | 18,000 |
| Navarra | 19,323 | 16,000 |
| Various | 815 | 3,000 |
| Totals | 7,419,758 | 7,125,600 |

* *Sud-Afrikanische Wochenschrift*, vol. vii. p. 1129.

† *Revista Minera*, vol. i. p. 84.

The following table shows the exports of iron ore in 1898, arranged according to the country to which the shipments were made. The figures show a decreased export of 326,000 metric tons. The exports to Holland consisted largely of cargoes in transit to Germany :—

| Destination. | 1897. | 1898. | Increase (+) or Decrease (-). |
|-------------------------|--------------|--------------|----------------------------------|
| | Metric Tons. | Metric Tons. | Metric Tons. |
| Great Britain | 5,091,027 | 4,748,557 | - 342,470 |
| Holland | 1,026,727 | 1,135,640 | + 108,913 |
| France | 435,972 | 399,424 | - 36,548 |
| Belgium | 224,776 | 201,693 | - 23,083 |
| Germany | 31,967 | 58,284 | + 16,317 |
| Austria | 10,350 | 8,650 | - 1,700 |
| United States | 59,243 | 5,792 | - 53,451 |
| Italy | ... | 20 | + 20 |
| Sweden | 4,526 | ... | - 4,526 |
| Totals | 6,884,588 | 6,558,060 | - 326,528 |

Coal.—Adriano Contreras * has collected the mineral statistics of Spain for 1898. The figures published are, of course, provisional, but they give a clear idea of the condition of the mining industry of Spain in 1898. In the case of coal, the principal statistics given are as follows :—

| | 1897. | 1898. |
|------------------------------|--------------|--------------|
| | Metric Tons. | Metric Tons. |
| Coal production | 2,019,400 | 2,466,800 |
| Lignite production | 54,232 | 59,800 |
| Coal imports | 1,633,333 | 1,215,554 |
| Coal exports | 298,520 | 321,739 |
| Coal consumption | 4,002,946 | 4,061,121 |

The Spanish coke statistics were as follows :—

| | 1897. | 1898. |
|-----------------------|--------------|--------------|
| | Metric Tons. | Metric Tons. |
| Production | 306,774 | 308,375 |
| Imports | 214,763 | 231,467 |
| Consumption | 521,537 | 539,842 |

The production of patent fuel in Spain last year showed an increase of 14 per cent. over that of the previous year. The output of the various provinces in 1898 was as follows:—

| | Metric Tons. |
|--------------------|--------------|
| Asturias | 145,693 |
| Palencia | 72,540 |
| Seville | 67,693 |
| Cordoba | 55,086 |
| Gerona | 30,000 |
| Leon | 18,000 |
| Total | 389,012 |

The production of anthracite showed an increase of 65 per cent. over that of the previous year. The output of the various provinces in 1898 was as follows:—

| | Metric Tons. |
|--------------------|--------------|
| Leon | 40,500 |
| Asturias | 18,000 |
| Cordoba | 11,000 |
| Palencia | 5,000 |
| Total | 74,500 |

The official mineral statistics show that in 1897 the production of mineral fuel in Spain was as follows:—

| | Tons. |
|----------------------|-----------|
| Coal | 2,010,960 |
| Lignite | 54,232 |
| Anthracite | 8,758 |
| Total | 2,073,950 |

There were 447 collieries, employing 11,709 men, 917 women, and 2217 children, and 121 steam-engines of an aggregate horse-power of 4194. The production of coke amounted to 755,394 tons, and that of briquettes to 333,272 tons.

Manganese Ore.—In 1895 the output of manganese ore in the province of Huelva, Spain, was only 10,162 tons. Since then it has risen to 92,000 tons a year, the rest of Spain yielding another 8000 tons. The most important mines in Huelva are the Isabel and the Resucitada, the latter forming a compact deposit over 30 yards in thickness, the ore containing—

| | | |
|------------|-------|-------------|
| Manganese. | Iron. | Silica. |
| 39·0 | 4·6 | 8·0 to 10·0 |

It is anticipated that the output of manganese ore in the Huelva province will increase to 200,000 tons a year. After calcination the ore

is separated into two classes, one of which contains from 40 to 47 per cent. of manganese and 10 to 13 of silica, and the other 30 to 34 of manganese and 18 to 20 of silica. In 1896, 60,176 tons of this poorer sort was used in Belgium and Luxemburg in the production of basic pig iron. The richer ore is used in the manufacture of ferro-manganese.

The annual output of manganese ore in the world does not exceed about 500,000 tons. In the extreme south-eastern portion of the island of Cuba there are deposits of manganese ore, containing some 53 per cent. of manganese and 4 of silica. Statistics are given for different years as to the production of manganese ore in other countries, Russia being the chief exporting country.*

XIII.—SWEDEN.

Production of Iron Ore.—The production of iron ore in Sweden in 1897 † comprised 2,086,119 tons of iron ore from mines and 1047 tons of lake and bog iron ore. The corresponding quantities for the previous year were respectively 2,038,094 tons and 925 tons. Of manganese ore 2749 tons were produced in 1897 as compared with 2056 tons in 1896, and of fireclay 112,283 tons in 1897 and 120,426 tons in 1896.

The number of producing iron ore mines increased from 326 in 1894 to 366 in 1897. The total number of workpeople employed at these mines numbered 8797. Of the iron ores raised, 88·9 per cent. was magnetite and 11·1 per cent. hæmatite, as compared respectively with 87·4 per cent. and 12·6 per cent. in the previous year. From old waste heaps 10 magnetic separators extracted 25,951 tons of marketable ore. The quantities of iron ore raised in some of the different provinces were as follows :—

| | 1897. | 1896. |
|-----------------------|--------------|--------------|
| | Metric Tons. | Metric Tons. |
| Kopparberg | 796,433 | 784,979 |
| Norrbottn | 627,798 | 609,087 |
| Orebro | 284,186 | 278,512 |
| Westmanland | 184,277 | 185,586 |

* *Glückauf*, vol. xxxiv. p. 224; *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlv. p. 760.

† *Kommerskollegii underdåniga berättelse*, 1898, p. 6.

The greatest increase was shown in Norrbotten, where the Gellivara deposits yielded 623,110 tons as compared with 604,357 tons in 1896. Norrbotten thus raised 30·09 per cent. of all the iron ore raised in Sweden in 1897, Kopparberg 38·18 per cent., and Örebro 13·62 per cent. In Jönköping no iron ore was raised either in 1896 or 1897.

Iron Trade Statistics.—In Sweden there were in 1898 in operation 109 blast-furnaces, 25 Bessemer converters, and 36 open-hearth furnaces. According to the returns of the Swedish Association of Ironmasters, the production of pig iron amounted to 522,200 tons, that of blooms to 197,700 tons, that of Bessemer ingots to 102,400 tons, and that of forged iron ingots to 152,500 tons.*

The iron mines and works in Sweden visited by the Iron and Steel Institute in 1898 are described by H. Ponthière † and F. Korb.‡

XIV.—SWITZERLAND.

Imports.—The imports of Switzerland have been given§ provisionally for 1898 as follows:—

| | Tons. | Value £. |
|--------------------------------|-----------|-----------|
| Coal | 1,300,000 | 1,400,000 |
| Coke | 130,000 | 180,000 |
| Iron and steel, all kinds | 266,450 | 2,350,000 |
| Pig iron | 79,000 | 270,000 |
| Rails, bars, and sheets, heavy | 88,400 | 540,000 |
| Do. do. light | 25,700 | 230,000 |
| Tin-plate | 11,100 | 240,000 |
| Black plates | 5,300 | 47,500 |
| Iron pipe | 8,625 | 120,000 |
| Castings . | 14,500 | 200,000 |
| Forgings | 4,720 | 85,000 |

Mineral Statistics.—According to the report of the Swiss Government Mine Inspector,|| there are in the whole of Switzerland

* *Comité des Forges*, Bulletin No. 1458.

† *Annales des Mines de Belgique*, vol. iv. Part I.

‡ *Zeitschrift des Vereines deutscher Ingenieure*, vol. xxxiii. pp. 584-585.

§ *Engineer*, vol. lxxxviii. p. 406.

|| *Rapports des Inspecteurs Fédéraux des Fabriques et des Mines*. Aarau, 1898.

127 mines and underground quarries. Of these, 20 are mines employing 459 workmen, and 107 underground quarries with 1405 workmen. Of the former category, 136 of the workmen are engaged in the Delsberg iron mine, and 83 in the Val de Travers asphalt mine. The production included 12,000 tons of iron ore.

XV.—UNITED STATES.

Iron Trade Statistics.—The American Iron Trade Association * reports the production of iron and steel in the United States in 1898 to have been as follows :—

| | Tons. |
|--|------------|
| Pig iron | 11,773,934 |
| Bessemer steel ingots | 6,609,017 |
| Bessemer steel rails | 1,976,702 |
| Basic open-hearth steel ingots | 1,569,412 |
| Acid open-hearth steel | 660,880 |
| Total open-hearth steel | 2,230,292 |
| All kinds of steel | 8,932,857 |
| All rolled iron and steel, including rails | 8,513,370 |

Tin-Plate Production.—The total production of black plates for the calendar year 1898 was 876,954,424 lbs. The total quantity of tin-plates made was 732,290,285 lbs., which is equivalent to 6,780,465 boxes of finished tin-plate.

The imports of tin and terne plates for the year 1898 were 149,576,525 lbs., which compares with 187,825,880 lbs. in 1897 and 266,943,267 lbs. in 1896. These figures show the steadily continuous decrease in the imports.†

Lake Superior Iron Ore.—A statement of the shipments of iron ore from the Lake Superior mines, compiled by G. A. Newett,‡ gives the following output by ranges for 1898 :—

* *Annual Statistical Report of the American Iron and Steel Association*, Philadelphia, 1899, p. 23.

† *Engineering and Mining Journal*, vol. lxxvii. p. 406.

‡ *Annual Statistical Report of the American Iron and Steel Association*, 1899, p. 30.

| | 1898. | Total to date. |
|-------------------------|------------|----------------|
| | Tons. | Tons. |
| Range | 3,125,039 | 52,378,261 |
| Mesabi Range | 4,613,766 | 16,964,158 |
| Range | 2,527,274 | 27,453,706 |
| Range | 1,265,142 | 11,763,858 |
| Gogebic Range | 2,498,461 | 25,545,484 |
| Miscellaneous | ... | 2,320 |
| als | 14,029,682 | 134,107,787 |

Anthracite.—At a meeting of the Anthracite Coal Operators' Association, John C. Haddock pointed out that the present rates of transportation on anthracite in Pennsylvania are unreasonable and unjust. The annual report of the Delaware, Lackawanna, and Western Railroad Company is a public proclamation of the great profits that result from the present rates. The loss in mining coal in 1897 is shown in that report to have been 214,723 dols. The loss on merchandise traffic was 500,774 dols., but the gain from coal traffic was 6,344,936 dols.

Coke.—According to the statistics collected by E. W. Parker* for the United States Geological Survey, there were in 1897 in the United States 47,668 coke-ovens, of which number Pennsylvania had 26,910, West Virginia 8404, Alabama 5365, Tennessee 1948, Virginia 1453, and Colorado 1273. Of by-product ovens in Pennsylvania there are 180 Otto-Hoffman, 73 Semet-Solvay, 30 Newton-Chambers, and 3 Slocum.

The first coke-ovens arranged for the collection of the by-products that were erected in the United States were twelve Semet-Solvay ovens, that were commenced at Syracuse in 1891, although they were not finished until two years later. In 1896 thirteen similar additional ovens were erected at this works. In consequence of the satisfactory results that followed from their use, twenty-five were erected at Sharon, Pennsylvania, and fifty at Dunbar, Fayette County. In 1896 an Otto-Hoffman plant was erected at Johnstown, and in the previous year thirty Newton-Chambers ovens were commenced at Latrobe. These are of the beehive type, arranged for by-product collection.

In the summer of 1898 † the erection of 400 new Otto-Hoffman ovens

* *United States Geological Survey. Nineteenth Annual Report, Part VI. pp. 545-642.*

† *Stahl und Eisen*, vol. xix. p. 155.

was commenced near Boston. These are to yield gas that is to be utilised for illuminating purposes. Of Semet-Solvay ovens 195 were also commenced—120 at Ensley, Alabama, and 75 at Wheeling, West Virginia. The large coke-oven plant in course of erection at Everett, Massachusetts, is to comprise 1200 Otto-Hoffman ovens, and Nova Scotia coal is to be used.

The records of shipments of Connellsville coke in 1898, according to the *Connellsville Courier*,* show a total output of 8,460,112 tons from 18,643 coke-ovens. This is the largest production yet recorded for the region, while the prices obtained render the revenue yielded nearly a million dollars more than in 1890, the record year, when coke was two dollars a ton.

Cost of Iron Manufacture.—In a presidential address C. Kirchhoff† deals with a decade of progress in the reduction of costs in the manufacture of iron and steel. In diagrammatic form are presented full details of the variations in each item of cost of the production of pig iron in a Southern and in an Eastern plant, and for the production of ingots. Other diagrams are also given, and the fluctuations are also set out in tabular form, and are discussed. Progress in the rolling-mill is also dealt with.

G. R. Dunell‡ discusses the prospective expansion in American shipbuilding.

The Joliet Works of the Federal Steel Company have made in their converters in one day 2150 tons of steel, of which 1185 tons was made in twelve hours. On the following day the billet-mill made 948 tons of billets. The rolling-mill made 708 tons of No. 5 bar iron in twenty-four hours.§

XVI.—COMPARATIVE TABLES.

The World's Production of Coal and Iron.—For the purposes of comparison, the following summary of the production of coal in the principal countries of the world is appended :—

* *Annual Statistical Report of the American Iron and Steel Association*, Philadelphia, 1899, p. 24.

† *Transactions of the American Institute of Mining Engineers*, 1899.

‡ *Engineering Magazine*, vol. xvii. pp. 105-114.

§ *Bulletin of the American Iron and Steel Association*, vol. xxxiii. p. 25.

| Country. | Year. | Production in Tons. |
|----------------------------------|-------|------------------------|
| United Kingdom . | 1898 | 202,042,243 |
| Australia— | | |
| New South Wales | 1897 | 4,383,591 |
| New Zealand . | 1897 | 840,713 |
| Queensland . | 1897 | 358,407 |
| Tasmania . | 1897 | 48,501 |
| Victoria | 1897 | 236,277 |
| Austria, coal | 1897 | 10,492,771 |
| " lignite | 1897 | 20,458,093 |
| Hungary, coal | 1897 | 1,118,025 |
| " lignite | 1897 | 3,870,530 |
| Belgium | 1898 | 22,075,093 |
| Borneo | 1897 | 41,587 |
| Canada | 1898 | 3,725,585 |
| Cape Colony | 1897 | 113,851 |
| France | 1898 | 32,439,786 |
| Germany, coal | 1898 | 96,279,992 |
| " lignite | 1898 | 31,648,498 |
| Holland | 1896 | 137,787 |
| India | 1897 | 4,063,127 |
| Italy, lignite | 1897 | 314,222 |
| Japan | 1896 | 5,249,916 |
| Mexico | 1896 | 253,104 |
| Natal | 1897 | 243,960 |
| Peru | 1892 | 2,000 |
| Portugal, anthracite | 1897 | 7,996 |
| " lignite | 1897 | 9,342 |
| Russia | 1898 | 10,250,000 |
| Servia | 1896 | 11,726 |
| South African Republic | 1898 | 1,953,026 |
| Spain | 1898 | 2,466,800 |
| Sweden | 1897 | 224,343 |
| United States | 1897 | 178,769,344 |

A similar summary showing the production of pig iron is as follows:—

| Country. | Year. | Production in Tons. |
|--------------------------|-------|------------------------|
| United Kingdom | 1898 | 8,631,151 |
| Austria | 1897 | 887,945 |
| Hungary | 1897 | 420,478 |
| Bosnia | 1897 | 16,000 |
| Belgium | 1898 | 979,101 |
| Canada | 1898 | 68,755 |
| France | 1898 | 2,534,427 |
| Germany | 1898 | 7,402,717 |
| Italy | 1897 | 8,393 |
| Japan | 1896 | 16,000 |
| Russia | 1898 | 2,223,000 |
| Spain | 1897 | 297,100 |
| Sweden | 1897 | 538,197 |
| United States | 1898 | 11,773,934 |

Coal Consumption.—The following details of coal production and consumption in the various countries of Europe have been published : *—

| Country. | Consumption per Inhabitant. | Proportion Consumed. | | | Annual Output per Miner. |
|-----------------|--------------------------------|----------------------|-----------|---------------------|--------------------------------|
| | | Native. | English | Other Countries. | |
| | | | | | |
| | Tons. | Per Cent. | Per Cent. | Per Cent. | Tons. |
| United Kingdom | 3·82 | 99·99 | ... | 0·01 | 268 |
| Sweden . | 0·46 | 9·93 | 87·13 | 2·94 | 130 |
| Germany | 1·51 | 92·34 | 5·63 | 2·03 | 271 |
| Belgium | 2·65 | 88·66 | 1·90 | 9·44 | 178 |
| France . | 0·98 | 73·08 | 11·50 | 15·33 | 200 |
| Spain . | ... | 40·54 | 48·21 | 2·25 | 112 |
| Austria-Hungary | ... | 64·42 | 1·05 | 34·57 | 117 |

Wages of Coal-Miners.—A comparison made by the *Age of Steel* † between the wages of coal-miners in the United States and Germany shows that, so far as living expenses go, the advantage is with the German mines. The yearly wages in dollars in different districts in the two countries are as follow :—

| United States. | | Germany. | |
|------------------------------------|-----|---------------------------|-----|
| Ohio | 192 | Upper Silesia | 190 |
| Pennsylvania, anthracite | 200 | Lower Silesia | 197 |
| Pennsylvania, bituminous | 250 | Aix-la-Chapelle | 239 |
| West Virginia | 277 | Dortmund | 282 |

Duty on Iron and Steel.—The *Bulletin* of the American Iron and Steel Association ‡ publishes a useful summary of the rates of duty imposed on iron and steel by France, Germany, Sweden, Italy, Belgium, Austria-Hungary, Russia, Canada, and Mexico.

* "Coal Tables," Parliamentary Paper No. 118 of Session 1899; *Revue Universelle des Mines*, vol. xlv. p. 217.

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